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To: Mr. M.R. Allen
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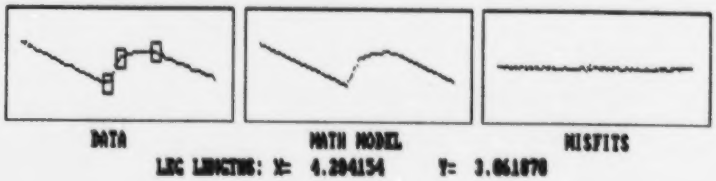
COMPUTER VISION FOR WELD INSPECTION

David L. Mader

The feasibility of using a commercial laser vision sensor for inspection of fillet welds has been demonstrated on a mockup test ring. A computer vision program was prepared to accept data from the sensor, analyse it, and determine weld leg lengths. Precision of measurement was more than adequate through use of a specially adapted least-squares curve fitting algorithm.

INTRODUCTION

A vision sensor system has been proposed for inspection of the bellows-ring to end fitting fillet weld in the Bruce West Shift operation using a commercial laser vision system. The system has a sensor head which incorporates a miniature video camera and a laser light projector that directs a sheet of light onto the work piece at right angles to the weld. A personal computer hosts a special purpose plug-in board that takes the two-dimensional image from the camera and extracts the weld profile in real-time. Analysis of the weld profile to derive quality assurance data on the weld has been done by a program written at the Research Division. The present software could be used as it stands for field inspection, though with some time penalty due to relatively slow execution speed. The algorithm could be streamlined for faster execution, and it could be implemented on a digital signal processing board for much higher speed.



The algorithm fits a mathematical model to the profile data as seen above and draws the small boxes on the data where it has found feature points. The major part of the program is devoted to obtaining this fit, which amounts to pattern recognition. Then weld leg lengths may be calculated.

job	file	date	report no.
16-183-451	819.36	June 7, 1988	88-131-K

89-02556/

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The misfits graph seen above plots the point by point difference between the observed profile data and the final fitted math model. As seen, this plot is essential flat for this case showing that a successful fit was obtained. Therefore the quoted leg lengths may be taken as reliable.

Sample runs of the analysis program are given in the Appendixes. Appendix I gives a run in Setup Mode which is used for initial setup or for debugging.

Appendix II shows the results of an Inspection Run that produced Table I for a weld test ring which included a wide range of outcomes of welding attempts. The table shows an identification header followed by weld leg lengths, combined thickness of bellows ring and gap to end fitting, and the average misfit seen on the graph of misfits. Provision for operator comments is also shown.

What is labelled as locations 1, 2, and 3 are three different measurements taken at the same location. Thus the differences seen in the measured values indicate that system noise is approximately +/- 0.1 mm. This shows that the math model fitting technique can provide relatively fine resolution even from the sensor head employed which was a wide field of view, low resolution head.

TABLE I. Sample results

Inspector: DAVE MADER
Channel #: PICKERING MOCKUP SCRAP RING
Date: 04-22-1988 Time: 15:51:26
Inspection locations from 1 to 22

Inspection location #	Leg lengths X	Leg lengths Y	Thickness (ring+gap)	Average misfit	
	mm	mm	mm	mm	
1	3.91	2.83	7.06	0.08	
2	3.94	3.06	7.01	0.09	
3	3.84	3.01	7.20	0.08	
4	4.22	4.20	6.92	0.08	
5	4.30	4.25	6.91	0.09	
6	4.45	4.66	6.78	0.08	
7	4.22	4.88	7.10	0.09	
8	4.16	5.03	6.70	0.10	
9	3.21	4.39	7.42	0.11	
10	3.77	5.46	7.68	0.11	
11	3.60	5.81	7.59	0.11	
12	3.62	6.29	7.83	0.12	
13	4.39	5.32	8.12	0.13	
14	4.60	4.88	8.53	0.12	
15	4.80	4.33	8.43	0.09	
16	5.76	1.07	6.34	0.36	Rejected by operator
17	5.92	1.15	4.32	0.64	Rejected by operator
18	7.35	0.78	5.51	0.27	
19	6.15	0.30	7.70	0.09	

Legitimate fillet welds were observed at locations 1 to 16, with leg length and thickness variations as reported in the table. Location 16 did indeed have a short Y leg. Locations 17, 18, and 19 actually had lack of fusion on the bellows ring and would have been rejected on the basis of the quoted Y leg length, and also on the basis of a large value for the average misfit.

PRINCIPLE OF WELDING VISION SENSOR AND PROFILE ANALYSIS

A structured lighting type of optical sensor described in /1/ was used to observe the bellows ring to end fitting fillet weld as indicated in Fig 1. Here a sheet of light from an infrared laser diode is projected on to the workpiece from the sensor head. Not shown in the figure is a miniature video camera, also enclosed in the sensor head, that looks downwards toward the stripe of laser light on the workpiece.

The weld leg lengths are defined in Fig 1 as:

1) X, the length of weld contact on the end fitting, and
2) Y, it's contact on the bellows ring and on the gap.

The total thickness is defined as the ring thickness plus the gap between the ring and end fitting. The leg lengths and total thickness are quantities which are directly accessible to measurement from an external point of view.

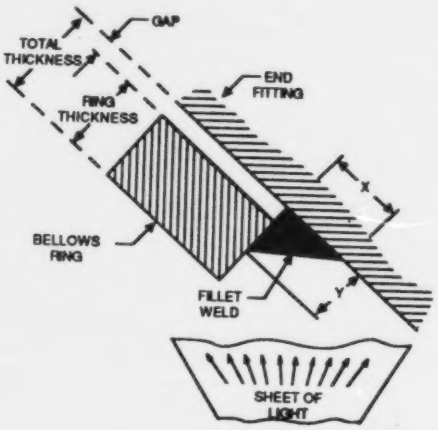


Fig 1. Workpiece is "sectioned" by a sheet of light.

The key points and surfaces on the workpiece revealed by light sectioning are shown in Fig 2.

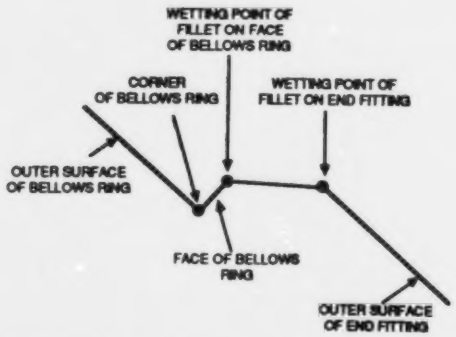

WETTING POINT OF FILLET ON FACE OF BELLOWS RING
CORNER OF BELLOWS RING
WETTING POINT OF FILLET ON END FITTING
OUTER SURFACE OF BELLOWS RING
FACE OF BELLOWS RING
OUTER SURFACE OF END FITTING

Fig 2. Profile of workpiece consists of four lines and three breakpoints.

Various fillet cross sections and gaps are sketched in Fig 3. These profiles are shown with equal leg lengths X and Y as defined above. Since it is clear that the strength of the joint in (b) and (d) is less than that of (a) and (c), a more sophisticated analysis may be warranted. For example, if the bellows ring thickness were read in to the program, then it could be subtracted from the total thickness to obtain the gap, which could then be subtracted from Y to obtain the true leg length of weld on the bellows ring.

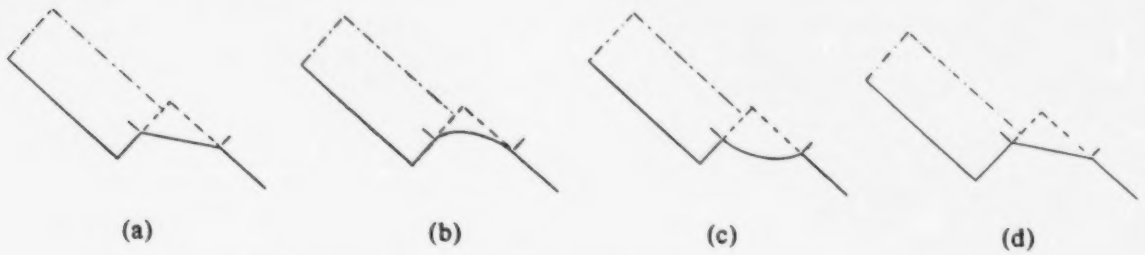


Fig 3. Fillet shape affects joint strength, as does gap size, for the same X and Y.

Two extreme cases of weld misalignment which did in fact occur on an early mockup test ring are shown in Fig 4, where the torch was too close to the ring in (a) and too far from it in (b). Case (b) would be identified as a rejectable weld from exterior leg length measurement alone. Case (a) would appear from an exterior examination to have sufficient contact with both the bellows ring and the end fitting. However, the actual contact with the end fitting is insufficient. This case would have to be detected separately by visual inspection, or with the present computer program by monitoring the absolute position of the apparent corner of the bellows ring. Excessive curvature of the fillet could also be monitored.

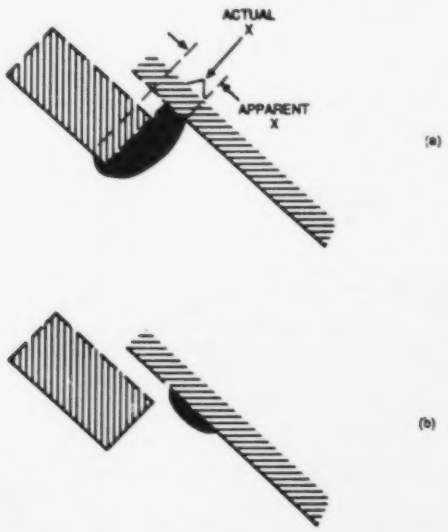
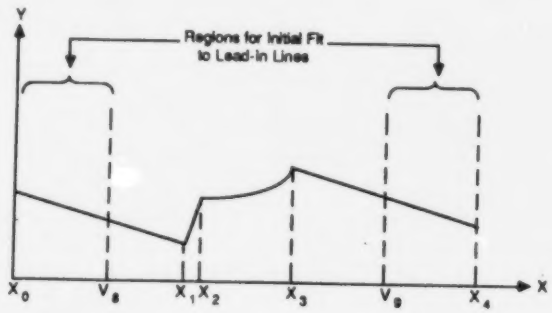


Fig 4. Torch tracking errors can put the weld in the wrong place.

Math Model. The mathematical model used in this work to emulate the light sectioning profiles seen on the workpiece is given in Fig 5. The expected profiles were segmented into four curves which join together at three intersection points herein referred to as breakpoints. The breakpoints located in Fig 5 at X_1, X_2, and X_3 are named in Fig 2 as the corner of the bellows ring, the wetting point of the weld on the face of the bellows ring, and the other wetting point on the surface of the end fitting.

The four curves for the four segments of the profile are taken as straight lines for the original surfaces, and a parabola of arbitrary curvature for the fillet weld. Applying the condition that the curves intersect at the specified breakpoints leads to solution for some of the slopes and intercepts. The remaining unknown parameters are listed in Fig. 5.

Fig 5 also serves to indicate the designation of various boundaries used to select data for different processing stages described in Appendix 1.



Math Model, $y = f(x)$

for

$X_0 < X \leq X_1$,	$f = a_1X + b_1$	line
$X_1 < X \leq X_2$,	$f = a_2X + b_2$	line
$X_2 < X \leq X_3$,	$f = a + bX + cX^2$	parabola
$X_3 < X \leq X_4$,	$f = a_4X + b_4$	line

where

$a_2 = -\frac{1}{a_1}$	for perpendicular line
$a_4 = a_1$	for parallel line
$b_2 = (a_1 - a_2)X_1 + b_1$	for lines intersecting at X_1

$$a = \frac{X_2X_3(a_2 - a_1) + X_3b_2 - X_2b_4 - c\left(\frac{X_2 - X_3}{2}\right)^2 (X_3 - X_2)}{X_3 - X_2}$$

$$b = \frac{a_2X_2 - a_1X_3 + b_2 - b_4}{X_2 - X_3}$$

for parabola intersecting lines at X_2 and X_3

Unknown parameters to be determined are:

$a_1, b_1, X_1, X_2, X_3, b_4, c$

Boundaries X_0, X_4, V_8, V_9 are set manually when system is installed.

Fig 5. A mathematical model was fitted to the data to obtain the unknown parameters needed for leg length calculation.

Least-Squares Curve Fitting. A least-squares curve fitting algorithm is included in the program given in Appendix III to automatically adjust the unknown parameters in the math model and obtain a good fit to the data. The fitting algorithm is suitable for finding the coefficients in the formulas for the lines and the parabola (which is straightforward), and for finding the breakpoints (which requires a "non-linear" least-squares program.)

CONCLUSIONS

The feasibility of using a commercial vision sensor for inspection of fillet welds has been demonstrated on a mockup test ring. A computer program was prepared to accept data from the sensor, analyse it, and determine weld leg lengths. Precision of measurement was more than adequate through use of a specially adapted least-squares curve fitting algorithm.

Further development work would consist of:

1. Adapting the program for field use by field operators in consultation with them.

2. Providing inspection results in graphical form in addition to the tabular form seen in Table I. Limits of acceptibility could be shown superposed on a histogram of results.

3. Improving the analysis algorithm for greater execution speed.

4. Performing a more sophisticated calculation of weld strength than exterior measured leg lengths.

5. The existing program written in Basic could be translated into the C language for possible incorporation into the existing commercial software.

6. The analysis program could be implemented on a digital signal processing board for real time response.

The author gratefully acknowledges the cooperation of the Welding Unit in the Metallurgical Research Department, which provided a laser sensor system for program development, and valuable background information. Thanks are extended to the supplier of the commercial sensor, MVS, for helpful discussions on certain aspects of a computer vision analysis approach.

Approved:

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Associate Research Scientist
Science Section

REFFERENCE

1. Mader, D.L., "Computer Vision for Robotic Welding," Ontario Hydro Research Report No 85-229-K, October 6, 1986.

APPENDIX I. SET-UP RUN

The computer output seen on the computer screen in the course of an initial set-up run is presented here to show the various processing options included in the program.

```
                PROGRAM WELD.BAS
FITS MODEL FOR WELD PROFILE TO OBSERVED PROFILE
                DAVID L. MADER
   ONTARIO HYDRO RESEARCH, TORONTO, CANADA M8Z 5S4
                April 21, 1988
 This program looks for a number of profiles in files named:
  P001, P002,...   P010, P011,...    P100, P101,.. up to P999

Q to quit

? Initial set-up (1) or inspection run (0) 1
? Parameter file: (e.g. PARAMS, or special one)? PARAMS
? Want to edit parameters (Y) Y

            INITIAL PARAMETER ESTIMATES
I                                                      PAR(I)
 1  Slope A1 of outer surfaces                        -.4703314
 2  Intercept B1 for bellows ring                      41.44544
 3  First breakpoint X1 at corner of weld ring         .3631626
 4  Second breakpoint X2 at wetting point on ring      1.615237
 5  Third breakpoint X3 at wetting point on end fitting 6.821677
 6  Intercept B4 of end fitting surface                50.47173
 7  Curvature of parabola C                           -4.022314E-02

CHANGE NO.?   TO ?    (0,0=NO CHANGES)? 0,0
I                                          JV(I)
 1  LBOX half length of side of box        4
 2  1 for choice on 3 graphs               0
 4  NPAR, no. parameters to scan           7
 5  Width for initial profile display box  300
 6  1 for pauses                           1
 7  Line number for message on 3 graphs    18
 8  Geometrical order. 0 if bellows on left, 1 if on right  0
 9  Width for final display boxes (e.g. 200)  170
10  Number of points off of line to designate breakpoint  2
11  Time delay to view graphics (under 32000)  10000
12  Do fitting on every ? data point (1 to 4)  1
            PROCESSING CHOICES
13  ? Want to fit lead-in lines (1)  1
14  ? Want automatic CORNER designation (1)  1
15  ? How many fitting iterations on CORNER (0,1,2)  1
16  ? Want automatic designation of WETTING points (1)  1
17  ? How many fitting iterations on WETTING points (0,1,2)  1
18  ? Want manual designation of all breakpoints (1)  0
19  ? How many fitting iterations on overall profile (0,1,2)  5
20  ? Source for initial parameters: previous profile (0), setup file (1)  1
21  Operator is asked if result is o.k. (1)  0
CHANGE NO. ?   TO ?   (0,0=NO CHANGE)? 19,1
CHANGE NO. ?   TO ?   (0,0=NO CHANGE)? 0,0
? Want to save these parameters (Y) N
? Done with setup (Y) N
? PROFILE FILE NAME (e.g. P001, or special) ? P004
```

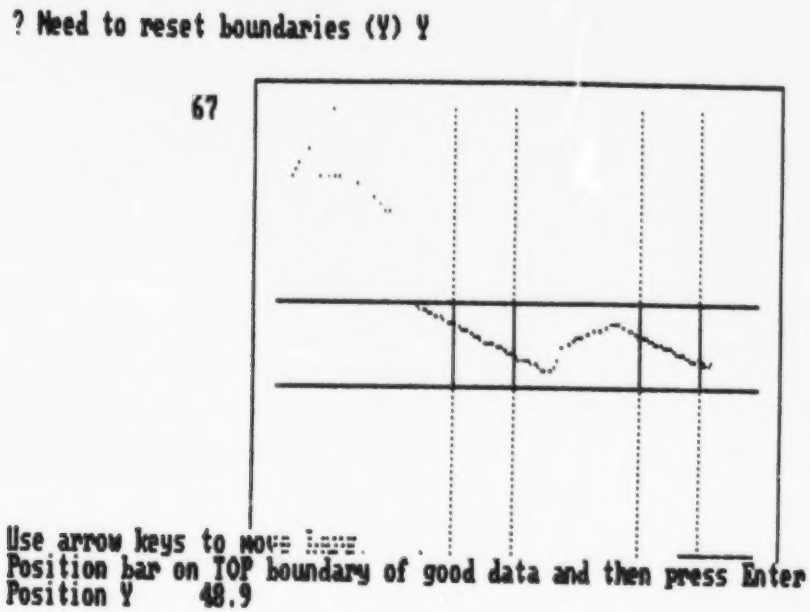

? Need to reset boundaries (Y) Y
67
Use arrow keys to move line.
Position bar on TOP boundary of good data and then press Enter
Position Y 48.9

Fig 6. Manual designation of boundaries. The left and right, and bottom and top boundaries for good data are set, along with the regions for fitting the lead-in lines at each side. This needs to be done only when the sensor head is first installed.

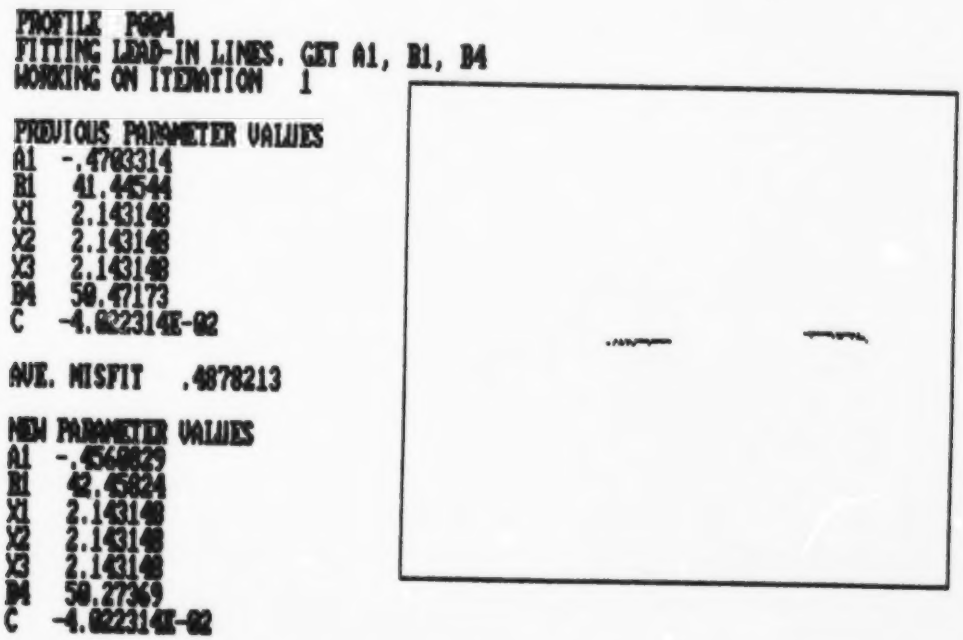


Fig 7. Fitting the lead-in lines at the left and right sides to obtain their slope A1, and intercepts B1 and B4.

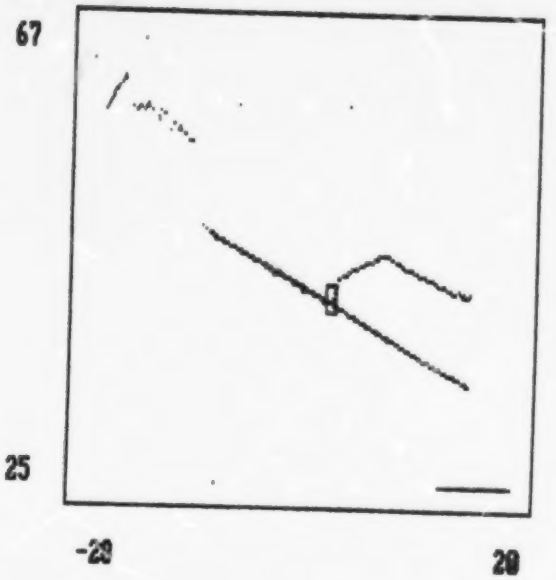


Fig 8. Automatic estimation of location of the corner of the bellows ring. The line previously fitted to the left lead-in line is superposed on the profile data. A small box has been drawn at a location where the data has started to deviate significantly from this line.

```
PROFILE  P004
FITTING CORNER BREAKPOINT  X1
WORKING ON ITERATION   1

PREVIOUS PARAMETER VALUES
A1   -.4560829
B1    42.45824
X1   -.2983334
X2    1.615237
X3    6.821677
B4    50.27369
C    -4.022314E-02

AVE. MISFIT    .292342

NEW PARAMETER VALUES
A1   -.4560829
B1    42.45824
X1   -.3197989
X2    1.615237
X3    6.821677
B4    50.27369
C    -4.022314E-02
```

Fig 9. One iteration of least-squares curve fitting was done in the region of the estimated corner breakpoint to fine tune its location. The graphics curve shows the misfit between data and math model prior to calculation of new parameter values.

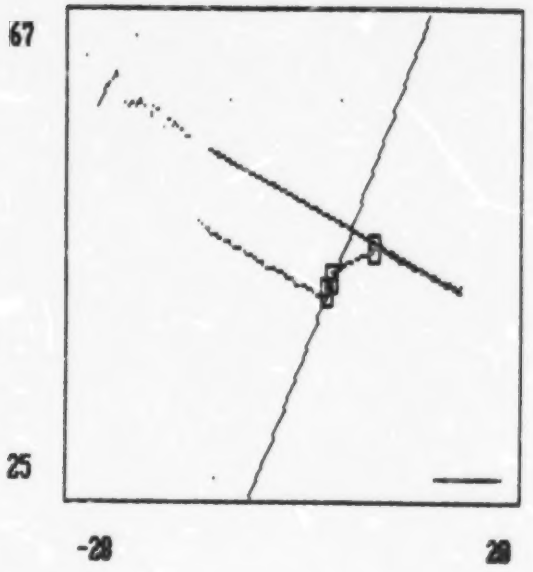


Fig 10. Automatic estimation of wetting points. Calculated lines are drawn for the face of the bellows ring, and the surface of the end fitting. A search was made along these two lines for deviations to the data that would indicate the locations of the wetting points where two small boxes were drawn. The corner point is also shown.

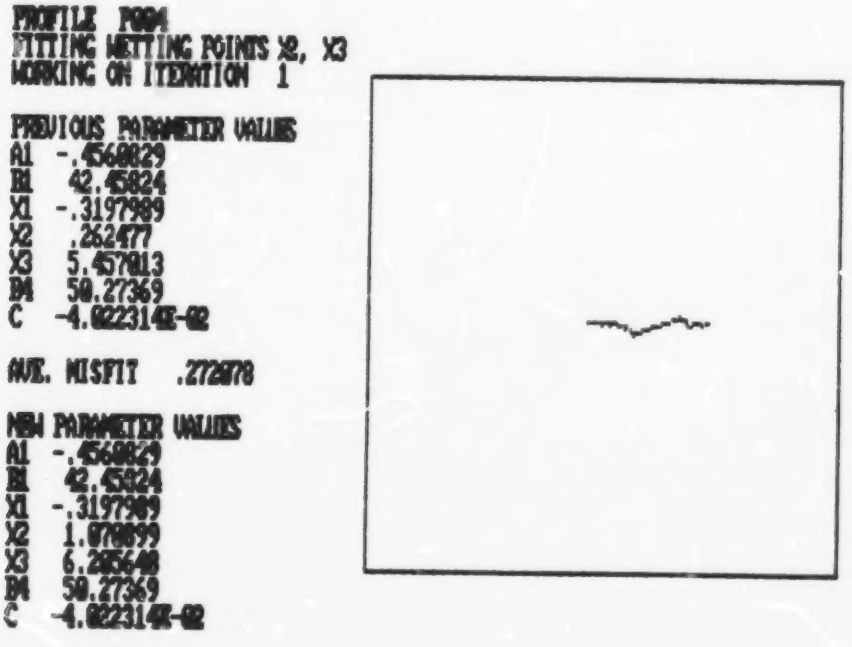


Fig 11. Fitting was done to fine tune the wetting points X2 and X3

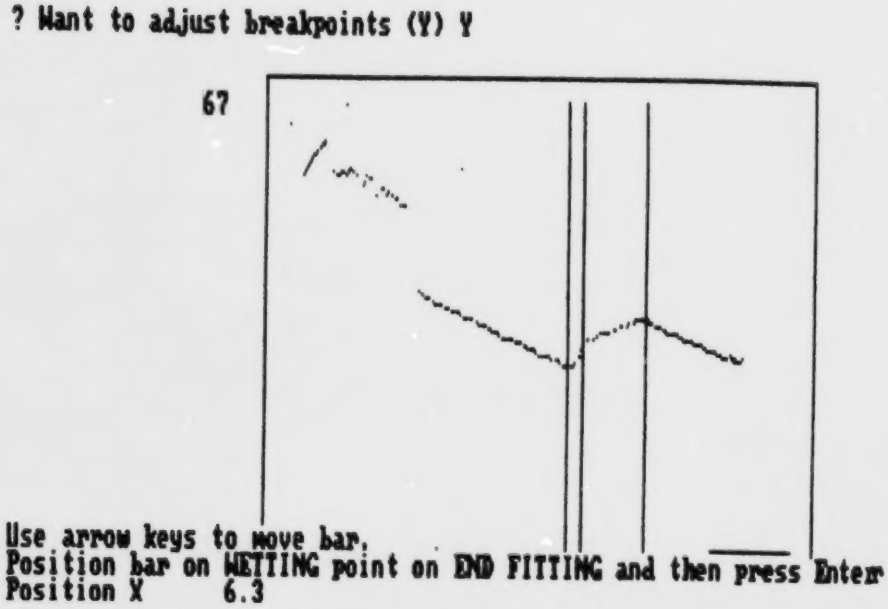

? Want to adjust breakpoints (Y) Y
67
Use arrow keys to move bar.
Position bar on WETTING point on END FITTING and then press Enter
Position X 6.3

Fig 12. Manual designation of breakpoints may be done if the operator is not satisfied with the automatic result. Normally this would be done only for pathological cases that the math model was not designed to handle.

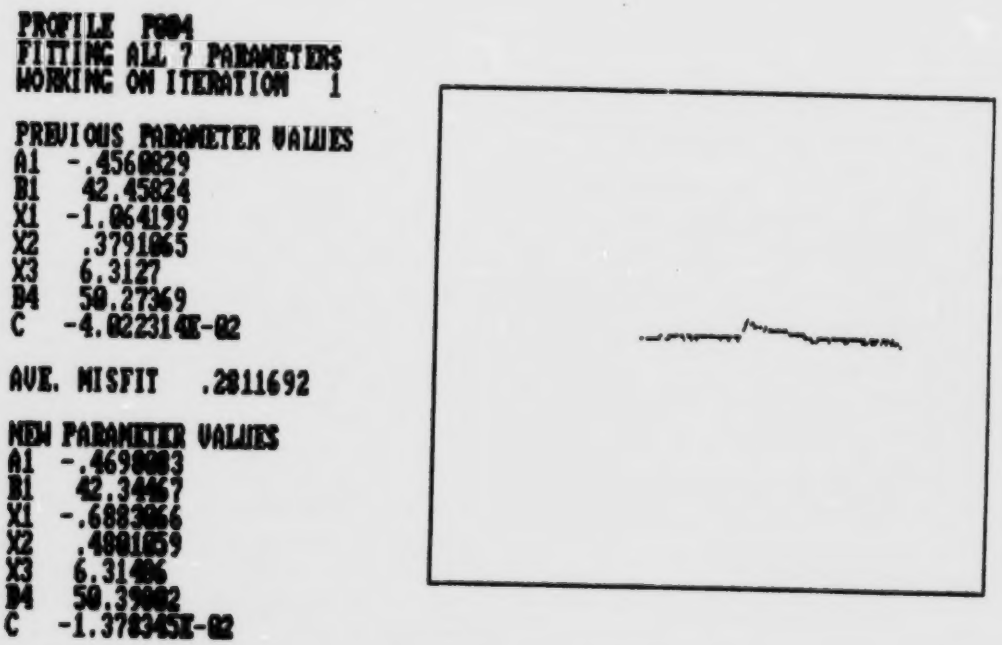


Fig 13. A global fitting run in which all unknown parameters in the math model are being varied to obtain the best fit. Changes can be seen in all parameter values after one iteration of fitting.

Fig 14. Final display of the result of fitting profile P004 shows that a good fit was obtained. The plot of misfits is flat showing that the math model agrees with the profile data. The average misfit is small, showing both a good fit and small noise in the data. The pattern recognition problem has been solved, since the computer has put the small boxes on the data profile in the same locations where a human would put them.

TABLE II. FINAL VALUES OF PROGRAM DATA

I	PAR	NHOLD	CONV	DER INC
1	-.4698083	0	.001	.001
2	42.34467	0	1	10
3	-.6883066	0	.1	.1
4	.4801059	0	.1	.1
5	6.31486	0	.1	.1
6	50.39802	0	1	1
7	-1.378345E-02	0	.001	.001

Average difference between
data and math model
9.319554E-02

DATE 04-22-1988 TIME 15:45:14

PROFILE FILE: P004

I	V	JV
1	-10.36551	4
2	14.6518	0
3	1000	5
4	4	7
5	41.06646	300
6	48.94929	1
7	1E-08	18
8	-4.271547	0
9	8.557844	170
10	.4	2
11	2	10000
12	0	1
13	0	1
14	0	1
15	0	1
16	0	1
17	0	1
18	0	0
19	0	1
20	0	1
21	0	0

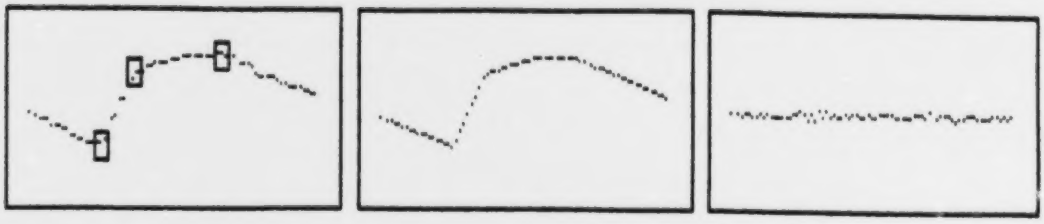
APPENDIX II. AN INSPECTION RUN

```
                    PROGRAM WELD.BAS
 FITS MODEL FOR WELD PROFILE TO OBSERVED PROFILE
                    DAVID L. MADER
    ONTARIO HYDRO RESEARCH, TORONTO, CANADA M8Z 5S4
                    April 21, 1988
 This program looks for a number of profiles in files named:
  P001, P002,..   P010, P011,..    P100, P101,.. up to P999

Q to quit

? Initial set-up (1) or inspection run (0) 0
TYPE IN NAME OF FILE TO STORE QA RESULTS IN : ? QA_RESUL
Append to previous results (Y), otherwise start over  N
Type in name of inspector? DAVE MADER
Type in channel number ? PICKERING MOCKUP SCRAP RING
? Inspection location to start at ? 1
? Inspection location to STOP at ? 22
```

RESULTS FILE after program has attempted to analyse 22 profiles.

```
Inspector: DAVE MADER
Channel #: PICKERING MOCKUP SCRAP RING
Date: 04-22-1988          Time: 15:51:26
Inspection locations from  1   to  22
```

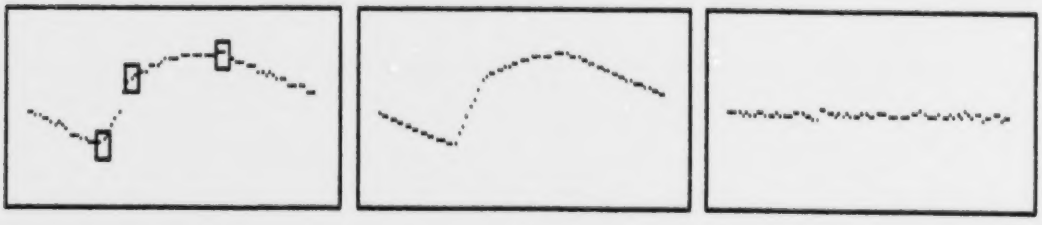
Inspection location #	Leg lengths X	Y	Thickness (ring+gap)	Average misfit	
	mm	mm	mm	mm	
1	3.91	2.83	7.06	0.08	
2	3.94	3.06	7.01	0.09	
3	3.84	3.01	7.20	0.08	
4	4.22	4.20	6.92	0.08	
5	4.30	4.25	6.91	0.09	
6	4.45	4.66	6.78	0.08	
7	4.22	4.88	7.10	0.09	
8	4.16	5.03	6.70	0.10	
9	3.21	4.39	7.42	0.11	
10	3.77	5.46	7.68	0.11	
11	3.60	5.81	7.59	0.11	
12	3.62	6.29	7.83	0.12	
13	4.39	5.32	8.12	0.13	
14	4.60	4.88	8.53	0.12	
15	4.80	4.33	8.43	0.09	
16	5.76	1.07	6.34	0.36	Rejected by operator
17	5.92	1.15	4.32	0.64	Rejected by operator
18	7.35	0.78	5.51	0.27	
19	6.15	0.30	7.70	0.09	



DATA MATH MODEL MISFITS

AVERAGE MISFIT .0838371

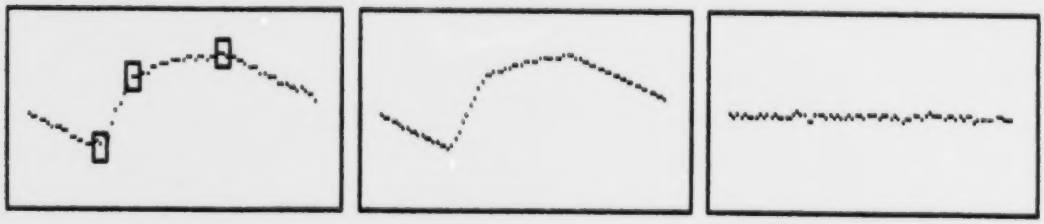
PROFILE FILE: P001
LEG LENGTHS: X= 3.91497 Y= 2.832731 THICKNESS= 7.063951



DATA MATH MODEL MISFITS

AVERAGE MISFIT 9.192175E-02

PROFILE FILE: P002
LEG LENGTHS: X= 3.943822 Y= 3.060864 THICKNESS= 7.006067



DATA MATH MODEL MISFITS

AVERAGE MISFIT 8.440836E-02

PROFILE FILE: P003
LEG LENGTHS: X= 3.844728 Y= 3.010034 THICKNESS= 7.196825

Fig 15. System noise is indicated by differences in output for profile files P001 to P003, which were all taken at the same location on the mockup welding sample ring. Precision of measurment is approximately +/- 0.1 mm.

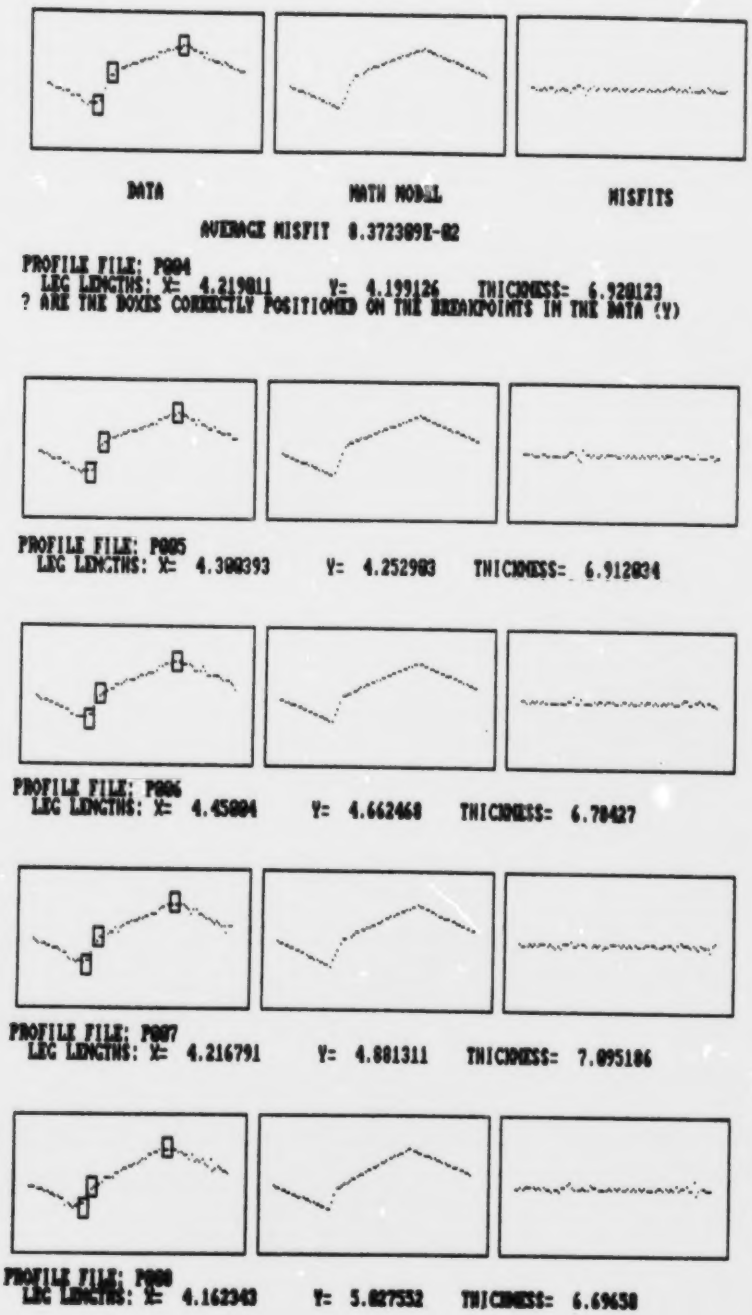

DATA
MATH MODEL
MISFITS
AVERAGE MISFIT 0.372309E-02
PROFILE FILE: P004
LEG LENGTHS: X= 4.219811 Y= 4.199126 THICKNESS= 6.920123
? ARE THE BOXES CORRECTLY POSITIONED ON THE BREAKPOINTS IN THE DATA (Y)
PROFILE FILE: P005
LEG LENGTHS: X= 4.300393 Y= 4.252983 THICKNESS= 6.912834
PROFILE FILE: P006
LEG LENGTHS: X= 4.45004 Y= 4.662468 THICKNESS= 6.78427
PROFILE FILE: P007
LEG LENGTHS: X= 4.216791 Y= 4.881311 THICKNESS= 7.095186
PROFILE FILE: P008
LEG LENGTHS: X= 4.162343 Y= 5.027552 THICKNESS= 6.69658

Fig 16. Several profiles were taken on an area where the fillet was increasing in size. The model does not provide a perfect fit because the mockup workpiece had a bevelled corner on the bellows ring that was not included in the model. The gap between the bellows ring and the end fitting was small in this area.

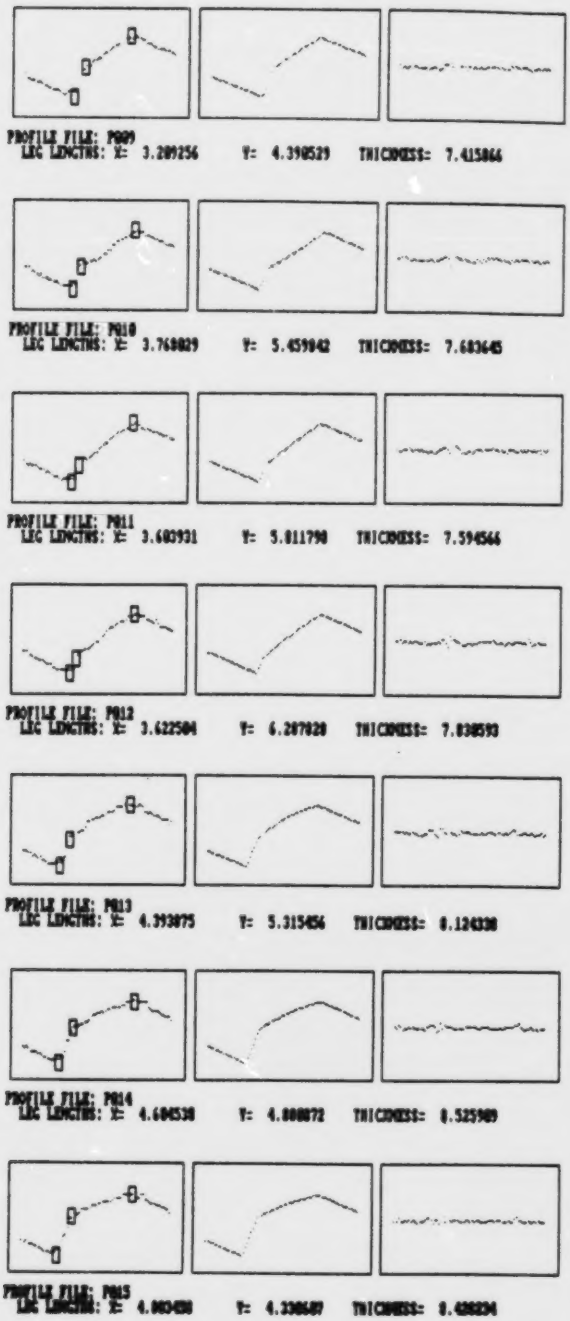
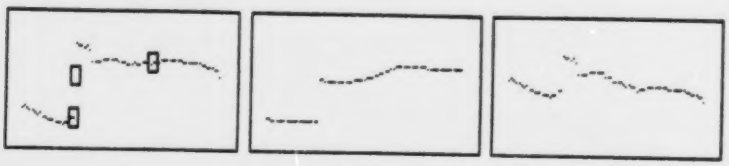


Fig 17. Two groups of profiles were taken at different locations on the mockup ring. Profiles P009 to P0012 show the weld bead riding up the bellows ring as Y increases. The remaining profiles taken in a different region on the opposite side of the mockup ring from those seen in the previous figure show a larger thickness because there was approximately a 1 mm gap which is included in the quoted thickness value.

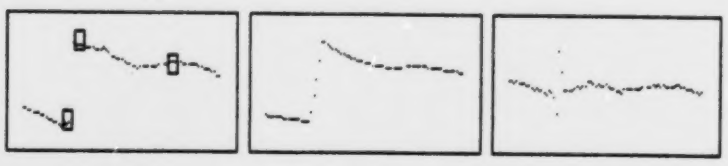
AVERAGE MISFIT .3592157

PROFILE FILE: P016
LEG LENGTHS: X= 5.764396 Y= 1.069811 THICKNESS= 6.23882
? ARE THE BOXES CORRECTLY POSITIONED ON THE BREAKPOINTS IN THE DATA (Y) N



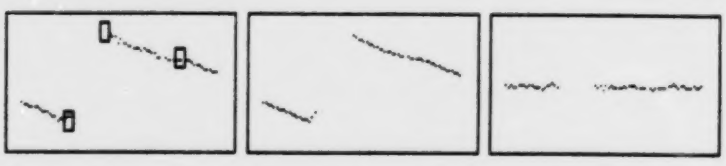
AVERAGE MISFIT .6353279

PROFILE FILE: P017
LEG LENGTHS: X= 5.924851 Y= 1.148273 THICKNESS= 4.320001
? ARE THE BOXES CORRECTLY POSITIONED ON THE BREAKPOINTS IN THE DATA (Y) N



AVERAGE MISFIT .2728193

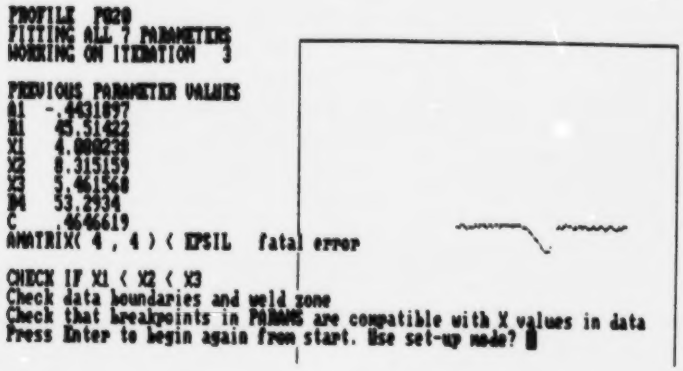
PROFILE FILE: P018
LEG LENGTHS: X= 7.35223 Y= .7701761 THICKNESS= 5.507774
? ARE THE BOXES CORRECTLY POSITIONED ON THE BREAKPOINTS IN THE DATA (Y)



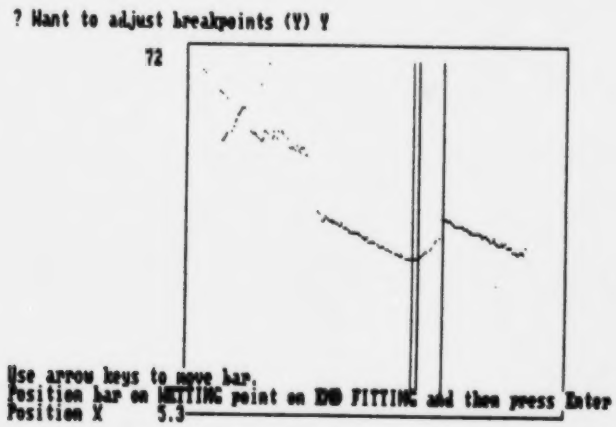
AVERAGE MISFIT 8.726747E-02

PROFILE FILE: P019
LEG LENGTHS: X= 6.14795 Y= .3943238 THICKNESS= 7.783516
? ARE THE BOXES CORRECTLY POSITIONED ON THE BREAKPOINTS IN THE DATA (Y)

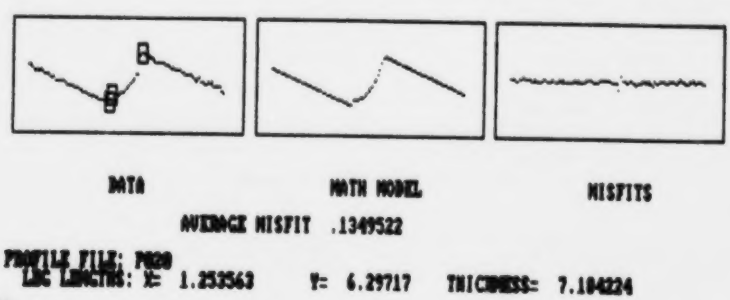
Fig 18. Failed welds were examined by the computer program with successful analysis results shown here. The analysis was successful if the program found numbers that would lead to rejection of the welds. A manual examination of the welds showed that P016 had a short Y leg, P017 and P018 had bad fusion on the bellows ring, and P019 had no fusion on the ring. In all of these cases the Y leg length measured by the computer would have lead to rejection.


PROFILE P020
FITTING ALL 7 PARAMETERS
WORKING ON ITERATION 3
PREVIOUS PARAMETER VALUES
A1 -.4431897
B1 45.51422
X1 4.000238
X2 8.315159
X3 5.461568
B4 53.2934
C .4646619
AMATRIX(4 , 4) < EPSIL fatal error
CHECK IF X1 < X2 < X3
Check data boundaries and weld zone
Check that breakpoints in PARAMS are compatible with X values in data
Press Enter to begin again from start. Use set-up mode?

a) Note that the program has gotten the position of the two wetting points X2 and X3 out of order, since X2 is supposed to be less than X3.

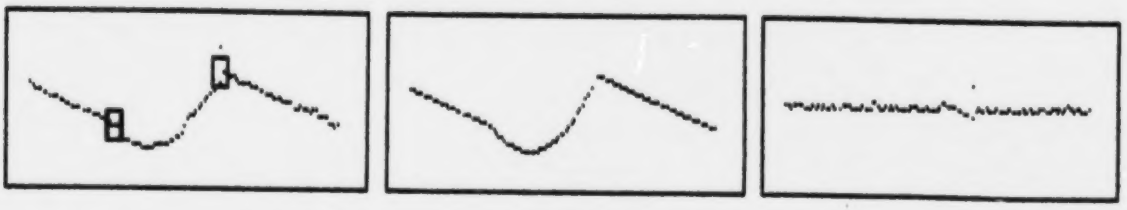

? Want to adjust breakpoints (Y) Y
72
Use arrow keys to move bar.
Position bar on WETTING point on END FITTING and then press Enter
Position X 5.3

b) To get a measurement of apparent leg lengths, manual designation of breakpoints was used.



c) Final result.

Fig 19. The computer program detected an impossible situation on a pathological weld. P020 was taken at a location where the weld overflowed the face of the bellows ring producing a wetting point on the outer surface of the bellows ring and hiding the corner point. The program gave guidance to the operator in a). In b) the operator performs a manual intervention, leading to a final result in c), where the fitting program grasped onto a noise fluctuation as the corner breakpoint, even though the corner was in fact hidden by a weld which had overflowed the bellows ring.



DATA MATH MODEL MISFITS

AVERAGE MISFIT .1294826

PROFILE FILE: P021
LEG LENGTHS: X= 5.710854 Y= 7.347413 THICKNESS= 7.20012
Press Enter to continue? ■

Fig 20. Another pathological case requiring operator intervention was P021 taken on an overflowed weld. Here the quoted leg lengths are well above the required minimum, whereas a manual inspection showed that there was no fusion on the end fitting.

PROFILE P022
FITTING ALL 7 PARAMETERS
WORKING ON ITERATION 2

PREVIOUS PARAMETER VALUES
A1 -.4330441
B1 44.93774
X1 -1.747048
X2 -1.943447
X3 5.887069
B4 53.24477
C .1432688

Division by zero at address 0C59:360B

D:\WELD>

Fig 21. Profile P022 was taken at a location where the welding had failed and the guide for the filler wire had fused to the workpiece and had been cut off leaving a projecting piece of wire. In this particular case the program was taken unawares and crashed leaving a system error message. Here we have an indication that when something goes wrong with the program, something had gone wrong with the weld.

APPENDIX III. SOURCE CODE FOR ALGORITHM IN BASIC

```
10 KEY OFF
20 REM  For use with MVS equipment to capture profiles.
30 REM  Model is for fillet weld on bellows ring to end fitting joint.
40 DIM PAR(30),V(30),JV(30),AMATRIX(15,15),E(15),DERIV(15),NHOLD(30),COV(30)
50 DIM DINC(30),X(240),PROFILE(240),MARKBREAK(3)
60 SCREEN 0 : CLS
70 PRINT "                PROGRAM WELD.BAS"
80 PRINT "FITS MODEL FOR WELD PROFILE TO OBSERVED PROFILE"
90 PRINT "                DAVID L. MADER
100 PRINT "  ONTARIO HYDRO RESEARCH, TORONTO, CANADA M8Z 5S4"
110 PRINT "                 April 21, 1988 "
120 PRINT " This program looks for a number of profiles in files named:"
130 PRINT "  P001, P002,..   P010, P011,..    P100, P101,.. up to P999"
140 PRINT"" : PRINT"Q to quit" : PRINT""
150 PRINT"? Initial set-up (1) or inspection run (0) ";
160 C$=INKEY$ : IF C$="" THEN GOTO 160
170 PRINT C$
180 IF C$ = "Q" OR C$ ="q" THEN CLOSE : PRINT "Quit" : END
190 IF C$ >< CHR$(48) AND C$ >< CHR$(49) THEN PRINT"try again": GOTO 150
200 IF C$=CHR$(48) THEN SETUP=0  : REM  false value
210 IF C$=CHR$(49) THEN SETUP=-1 : REM  true value
220 SETUPSAV=SETUP : REM  for use after error recovery
230 REM
240 REM ************************************************************************
250 REM                          MAIN
260 REM ************************************************************************
270 REM
280 IF SETUP THEN PROFILESTART=1 : PROFILESTOP=1 : JV(20)=1 : GOTO 470
290 REM  skip header for setup
300 INPUT "TYPE IN NAME OF FILE TO STORE QA RESULTS IN : ";QA$
310 PRINT"Append to previous results (Y), otherwise start over  ";
320 GOSUB 6950 : REM  Get answer
330 IF YES THEN OPEN "A",1,QA$ : REM  open a file for output, append
340 IF NO THEN OPEN "O",1,QA$ : REM  open a file for output, overwrite
342 PRINT #1,"This is file: ";QA$
350 INPUT"Type in name of inspector";C$ : PRINT #1,"Inspector: ";C$
360 INPUT"Type in channel number ";C$ : PRINT #1,"Channel #: ";C$
370 PRINT #1,"Date: ";DATE$;"        Time: ";TIME$
380 INPUT"? Inspection location to start at ";PROFILESTART
390 INPUT"? Inspection location to STOP at ";PROFILESTOP
400 PRINT #1,"Inspection locations from ";PROFILESTART;"  to ";PROFILESTOP
410 PRINT #1,"" : REM  leave a blank line
420 PRINT #1,"Inspection    Leg lengths     Thickness    Average"
430 PRINT #1,"location #    X        Y     (ring+gap)   misfit"
440 PRINT #1,"              mm       mm       mm         mm"
450 CLOSE #1
460 GOSUB 2940 : REM  Read in parameters for inspection run
470 REM ************************************************************************
```

```
480 FOR IPROFILE=PROFILESTART TO PROFILESTOP
490 IF JV(20)=1 THEN GOSUB 2940 : REM Read in parameters from file, or previous
500 IF NOT SETUP THEN JV(6)=0 : REM no pauses when fitting
510 IF NOT SETUP THEN GOTO 560
520 GOSUB 3110 : REM  Edit parameters
530 PRINT "? Done with setup (Y) ";
540 GOSUB 6950 : REM  Get answer
550 IF YES THEN GOTO 150
560 ZONEL=V(8) : ZONER=V(9)
570 GOSUB 1580 : REM  Read input data profile
580 IF SETUP THEN GOSUB 7840 : REM  Manual setting of boundaries
590 REM
600 REM *** first fitting pass to fit lead-in lines at each side of profile ***
610 IF JV(13) = 0 THEN GOTO 760 : REM skip this
620 MESSAGE$="FITTING LEAD-IN LINES. GET A1, B1, B4"
630 NHOLD(1)=0 : NHOLD(2)=0 : NHOLD(3)=1 : NHOLD(4)=1 : NHOLD(5)=1
640 NHOLD(6)=0 : NHOLD(7)=1
650 MAXIT=JV(13) : REM get perfect fit in 1 iteration, no breakpoints involved
660 X0=V(1) : X4=V(2) : REM  outer boundaries for fitting
670 ZONEL=V(8) : ZONER=V(9) : REM  inner dead zone for fitting
680 DELTAX=JV(12) : REM  step size in going through points
690 REM  put all breakpoints inside ZONE, otherwise theory may exclude leadins
700 SAVPAR3=PAR(3) : SAVPAR4=PAR(4) : SAVPAR5=PAR(5)
710 CENTER=(V(8)+V(9))/2
720 PAR(3)=CENTER : PAR(4)=CENTER : PAR(5)=CENTER
730 GOSUB 4490 :REM  Perform fitting. Find slope and intercepts of leadin lines
740 PAR(3)=SAVPAR3 : PAR(4)=SAVPAR4 : PAR(5)=SAVPAR5
750 REM
760 REM ******** automatic designation of CORNER breakpoint *******
770 IF JV(14) >< 1 THEN GOTO 830 : REM  skip this
780 REM  Note that corner position is usually the same from one profile to next
790 GOSUB 1910 : REM  Show profile
800 GOSUB 6100 : REM  automatic designation of the corner breakpoint
810 FOR I=1 TO JV(11) : NEXT : REM  time delay to view graphics
820 REM
830 REM ******* second fitting pass to fine tune breakpoint at CORNER *******
840 IF JV(15) = 0 THEN GOTO 930 : REM  skip fine tuning
850 MESSAGE$="FITTING CORNER BREAKPOINT  X1"
860 NHOLD(1)=1 : NHOLD(2)=1 : NHOLD(3)=0 : NHOLD(4)=1 : NHOLD(5)=1
870 NHOLD(6)=1 : NHOLD(7)=1 : MAXIT=JV(15)
880 IF ORDER THEN X0=V(8) : ZONEL=PAR(3)+V(11) : ZONER=V(2) : X4=V(2)
890 IF NOT ORDER THEN X0=V(1) : ZONEL=V(1) : ZONER=PAR(3)-V(11) : X4=V(9)
900 DELTAX=1 : REM  liable to miss sensitive area with bigger step size
910 GOSUB 4490 : REM  Perform fitting for corner region
920 REM
930 REM ********** automatic designation of WETTING points ******************
940 IF JV(16) >< 1 THEN GOTO 1000 : REM  skip this
950 GOSUB 1910 : REM  Show profile
960 GOSUB 7050 : REM  automatic designation of wetting points
970 REM  time delay to view graphics
```

```
980 IF NOT SETUP THEN FOR I=1 TO JV(11) : NEXT
990 REM
1000 REM ********** fitting for wetting points **********
1010 IF JV(17) = 0 THEN GOTO 1090 : REM  skip this
1020 MESSAGE$="FITTING WETTING POINTS X2, X3"
1030 NHOLD(1)=1 : NHOLD(2)=1 : NHOLD(3)=1 : NHOLD(4)=0 : NHOLD(5)=0
1040 NHOLD(6)=1 : NHOLD(7)=1 : MAXIT=JV(17)
1050 X0=V(8) : X4=V(9) : ZONEL=V(8) : ZONER=V(8) : REM  fit between V(8), V(9)
1060 DELTAX=JV(12) : REM  speed up fitting by reducing number of points
1070 GOSUB 4490 : REM  Perform fitting. Find wetting points
1080 REM
1090 REM ********** manual designation of all breakpoints **********
1100 IF NOT SETUP AND JV(18) >< 1 THEN GOTO 1140 : REM  skip this
1110 GOSUB 1910 : REM  Show profile
1120 GOSUB 6680 : REM  manual designation
1130 REM
1140 REM ********** fourth fitting pass to fit everything **********
1150 IF JV(19) = 0 THEN GOTO 1250 : REM  skip this
1160 MESSAGE$="FITTING ALL 7 PARAMETERS"
1170 NHOLD(1)=0 : NHOLD(2)=0 : NHOLD(3)=0 : NHOLD(4)=0 : NHOLD(5)=0
1180 ZONEL=V(8) : ZONER=V(8) : REM no dead zone
1190 NHOLD(6)=0 : NHOLD(7)=0 : MAXIT=JV(19)
1200 X0=V(1) : X4=V(2)
1210 ZONEL=V(8) : ZONER=V(8) : REM no dead zone
1220 DELTAX=JV(12) : REM  speed up fitting by reducing number of points
1230 GOSUB 4490 : REM  Perform fitting. Fine tune all 7 parameters
1240 REM
1250 REM ********** Draw graphs of final results **********
1260 GOSUB 2070
1270 GOSUB 2640 : REM  show leg lengths and save on disk
1280 REM
1290 REM ********** assemble final table of results **********
1300 PRINT "  I";TAB(5);"PAR";TAB(19);"NHOLD";TAB(29);"CONV";
       TAB(39);"DER INC";TAB(50);"I";TAB(55);"V";TAB(65);"JV"
1310 FOR I=1 TO 7 : REM  up to 20 fits screen
1320 PRINT I;TAB(5);PAR(I);TAB(19);NHOLD(I);TAB(29);COV(I);TAB(39);DINC(I)
1330 NEXT I
1340 PRINT"" : PRINT"Average difference between" : PRINT"data and math model"
1350 PRINT"  ";MISFIT
1360 PRINT"" : PRINT "DATE ";DATE$;"  TIME ";TIME$
1370 PRINT"" : PRINT "PROFILE FILE: ";INPNAM$
1380 FOR I=1 TO 21
1390 LOCATE I+1,50
1400 PRINT I;TAB(55);V(I);TAB(65);JV(I);
1410 NEXT I
1420 REM
```

```
1430 REM ********** Continue on **********
1440 IF NOT SETUP THEN GOTO 1500
1450 GOSUB 3960 : REM  Save parameters
1460 PRINT "? Done with fitting on this profile (Y) ";
1470 GOSUB 6950 : REM  Get answer
1480 IF NO THEN GOTO 510
1490 SETUP=SETUPSAV
1500 C$=INKEY$ : IF C$="Q" OR C$="q" THEN PRINT"Quit batch run" : GOTO 1520
1510 NEXT IPROFILE
1520 PRINT "? Another run of this program (Y) ";
1530 GOSUB 6950 : REM  Get answer
1540 IF YES THEN GOTO 60
1550 CLOSE : END
1560 REM
1570 REM
1580 REM **********
1590 REM                Read data profile
1600 REM **********
1610 REM screen size and pixel border for box
1620 PB=6
1630 II=639-2*PB-1 : REM screen width an Compaq
1640 NN=199-2*PB-1 : REM   "   height  "   "
1650 REM  read experimental data from disk
1660 REM  convert IPROFILE to character string
1670 A!=IPROFILE : GOSUB 7690
1680 INPNAM$="P"+A$
1690 IF SETUP THEN INPUT "? PROFILE FILE NAME (e.g. P001, or special) ";INPNAM$
1700 OPEN "I",1,INPNAM$
1710 INPUT#1,NP : REM  from MVS sensor system
1720 REM  read data
1730 FOR I=1 TO NP : INPUT#1,X(I),PROFILE(I) : NEXT
1740 CLOSE #1
1750 REM  find max and min in data for autoranging
1760 XMIN=1E+10 : XMAX=-1E+10 : YMIN=1E+10 : YMAX=-1E+10
1770 FOR I=1 TO NP
1780 IF X(I) < XMIN THEN XMIN=X(I)
1790 IF X(I) > XMAX THEN XMAX=X(I)
1800 IF PROFILE(I) < YMIN THEN YMIN=PROFILE(I)
1810 IF PROFILE(I) > YMAX THEN YMAX=PROFILE(I)
1820 NEXT I
1830 REM  scale factors for axes
1840 LX=JV(5) : REM  horizontal side of box
1850 XSCALE=LX/(XMAX-XMIN)
1860 YSCALE=XSCALE/2 : REM  vertical expansion is 1 with Compaq Basic
1870 LY=YSCALE*(YMAX-YMIN)
1880 IS=INT(II/2-LX/2)
1890 NS=INT(NN/2+LY/2)
1900 RETURN
```

```
1910 REM ************************************************************************
1920 REM                      Show profile
1930 REM ****************************************
1940 SCREEN 2 : CLS
1950 LINE (IS-2*PB-2,NS-LY-PB-1)-(IS+LX+2*PB+2,NS+PB+1),,B : REM  draw box
1960 LOCATE NS*22/NN+4,IS*80/II : PRINT INT(XMIN)
1970 LOCATE NS*22/NN+1,IS*80/II-7 : PRINT INT(YMIN)
1980 LOCATE (NS-LY)*22/NN+1,IS*80/II-7 : PRINT INT(YMAX)
1990 LOCATE NS*22/NN+4,(IS+LX)*80/II-2 : PRINT INT(XMAX)
2000 REM $$  LOCATE NS*22/NN+4,(IS+LX/2)*80/II-2 : PRINT "MM"
2010 FOR K=1 TO NP
2020 I=INT( (X(K)-XMIN)*XSCALE ) : REM  Rotated 90 degrees CCW from MVS
2030 J=INT( (PROFILE(K)-YMIN)*YSCALE )
2040 PSET(IS+I,NS-J)
2050 NEXT K
2060 RETURN
2070 REM************************************************************************
2080 REM        Draw graphs of final results.
2090 REM****************************************
2100 REM Observed profile is in PROFILE
2110 IF JV(2) >< 1 THEN GOTO 2150
2120 PRINT"? Want the 3 graphs (Y) ";
2130 GOSUB 6950 : REM  Get answer
2140 IF NO THEN RETURN
2150 SCREEN 2 : KEY OFF : CLS : REM  high res graphics on Compaq screen
2160 LX3=JV(9) : X0=V(1) : X4=V(2)
2170 XSCALE3=LX3/(X4-X0)
2180 YSCALE3=XSCALE3/2 : REM  vertical expansion is 1 with Compaq Basic
2190 LY3=YSCALE3*(V(6)-V(5))
2200 NS=INT(NN/2+LY3/2)
2210 IS1=INT(II/6-LX3/2)          : REM  for Compaq screen
2220 IS2=INT(II/2-LX3/2)
2230 IS3=INT(5*II/6-LX3/2)
2240 IF LX3 > 200 THEN GOTO 2280 : REM  box too wide
2250 LINE(IS1-2*PB-2,NS-LY3-PB-1)-(IS1+LX3+2*PB+2,NS+PB+1),,B
2260 LINE(IS2-2*PB-2,NS-LY3-PB-1)-(IS2+LX3+2*PB+2,NS+PB+1),,B
2270 LINE(IS3-2*PB-2,NS-LY3-PB-1)-(IS3+LX3+2*PB+2,NS+PB+1),,B
2280 SUM=0 : INCLUDED=0
2290 FOR K=1 TO NP
2300 XX=X(K)
2310 IF XX < X0 OR XX > X4 THEN GOTO 2480
2320 IF PROFILE(K) < V(5) OR PROFILE(K) > V(6) THEN GOTO 2480
2330 GOSUB 4090 : REM  subroutine Theory
2340 DIFF=PROFILE(K)-F : ABSDIFF=ABS(DIFF)
2350 IF ITERATIONS=1 AND ABSDIFF > V(3) THEN GOTO 2480 : REM  one fitting pass
2360 IF ITERATIONS > 1 AND ABSDIFF > V(4) THEN GOTO 2480 : REM  more than one
2370 REM **** Plot data ******
2380 I=INT( (XX-X0)*XSCALE3 ) : REM  Rotated 90 degrees CCW from MVS
2390 J=INT( (PROFILE(K)-V(5))*YSCALE3 )
2400 PSET((I-1)+IS1,NS-(J-1))
```

```
2410 REM **** Plot theory ****
2420 J=INT( (F-V(5))*YSCALE3 )
2430 PSET((I-1)+IS2,NS-(J-1))
2440 REM **** Plot differences (misfits) ****
2450 J=INT( DIFF*YSCALE3 )
2460 PSET( (I-1)+IS3 , NS-LY3/2-J )
2470 SUM=SUM+ABSDIFF : INCLUDED=INCLUDED+1
2480 NEXT K
2490 REM  Mark key points: bellows ring corner, wetting points
2500 FOR K=3 TO 5
2510 XX=PAR(K) : GOSUB 4090
2520 XX=INT((XX-V(1))*XSCALE3)-1
2530 IBOX=IS1+XX : JBOX=NS+1-INT((F-V(5))*YSCALE3)
2540 LINE(IBOX-LBOX,JBOX-LBOX)-(IBOX+LBOX,JBOX+LBOX),,B
2550 NEXT K
2560 IF INCLUDED=0 THEN CLOSE
          : PRINT"ERROR in final results- NO POINTS INCLUDED" : END
2570 MISFIT=SUM/INCLUDED
2580 LOCATE JV(7),1
2590 PRINT TAB(12);"DATA";TAB(36);"MATH MODEL";TAB(64);"MISFITS"
2600 LOCATE JV(7)+2,20 : PRINT "AVERAGE MISFIT ";MISFIT
2610 PRINT ""
2620 PRINT "PROFILE FILE: ";INPNAM$
2630 RETURN
2640 REM ************************************************************************
2650 REM     Calculate leg lengths: XL, YL and thickness of bellows ring
2660 REM ************************************************************************
2670 A1=PAR(1) : REM  slope of line 1
2680 B1=PAR(2) : REM  intercept      "
2690 X1=PAR(3) : REM  first breakpoint
2700 X2=PAR(4) : REM  second breakpoint, wetting point of fillet on ring
2710 X3=PAR(5) : REM  third breakpoint, wetting point of fillet on endfitting
2720 B4=PAR(6) : REM  intercept of end fitting surface
2730 A2=-1/A1  : REM  slope of line 2
2740 Y1=A1*X1+B1
2750 B2=X1*(A1-A2)+B1
2760 XI=(B4-B2)/(A2-A1) : YI=A2*XI+B2 : REM  intersection of line 2 and 4
2770 Y3=A1*X3+B4 : Y2=A2*X2+B2
2780 XL=SQR((X3-XI)^2+(Y3-YI)^2) : REM  fillet leg length on end fitting
2790 YL=SQR((XI-X2)^2+(YI-Y2)^2) : REM  fillet leg length on bellows ring
2800 THICKNESS=SQR((X1-XI)^2+(Y1-YI)^2)
2810 PRINT "  LEG LENGTHS: X= ";XL;"     Y= ";YL;"   THICKNESS= ";THICKNESS
2820 IF SETUP THEN INPUT"Press Enter to continue";C$ : GOTO 2920
2830 OPEN "A",1,QA$: REM  open file with name stored in QA$ and append new data
2840 PRINT #1,USING"   ###   ";IPROFILE;
2850 PRINT #1,USING"######.##  ";XL;YL;THICKNESS;MISFIT;
2860 IF JV(21) =0 THEN GOTO 2900 : REM  skip operator involvement
2870 PRINT "? ARE THE BOXES CORRECTLY POSITIONED ON THE BREAKPOINTS IN
        THE DATA (Y)";
2880 GOSUB 6950 : REM  Get answer
```

```
2890 IF NO THEN PRINT #1,"   Rejected by operator";
2900 PRINT #1,"" : REM  to put in carriage return/line feed
2910 CLOSE #1
2920 SCREEN 0 : REM  text mode on screen
2930 RETURN
2940 REM*****************************************************************************
2950 REM                        Read parameters
2960 REM*****************************************
2970 NAR=30
2980 PAR$="PARAMS"
2990 IF SETUP THEN INPUT "? Parameter file: (e.g. PARAMS, or special one)";PAR$
3000 OPEN "I",1,PAR$
3010 FOR I=1 TO NAR : INPUT#1,PAR(I) : NEXT
3020 FOR I=1 TO NAR : INPUT#1,V(I) : NEXT
3030 FOR I=1 TO NAR : INPUT#1,JV(I) : NEXT
3040 FOR I=1 TO NAR : INPUT#1,NHOLD(I) : NEXT
3050 FOR I=1 TO NAR : INPUT#1,DINC(I) : NEXT
3060 FOR I=1 TO NAR : INPUT#1,COV(I) : NEXT
3070 CLOSE#1
3080 ORDER=JV(8)-1 : REM  -1 for bellows ring on right, 0 for left side
3090 LBOX=JV(1) : X0=V(1) : X4=V(2)
3100 RETURN
3110 REM *****************************************************************************
3120 REM                          Edit parameters
3130 REM *****************************************
3140 PRINT "? Want to edit parameters (Y) ";
3150 GOSUB 6950 : REM  Get answer
3160 IF NO THEN RETURN
3170 PRINT"" : PRINT"              INITIAL PARAMETER ESTIMATES"
3180 PRINT"I                                                  PAR(I)"
3190 PRINT" 1  Slope A1 of outer surfaces                        ";PAR(1)
3200 PRINT" 2  Intercept B1 for bellows ring                     ";PAR(2)
3210 PRINT" 3  First breakpoint X1 at corner of weld ring          ";PAR(3)
3220 PRINT" 4  Second breakpoint X2 at wetting point on ring       ";PAR(4)
3230 PRINT" 5  Third breakpoint X3 at wetting point on end fitting ";PAR(5)
3240 PRINT" 6  Intercept B4 of end fitting surface               ";PAR(6)
3250 PRINT" 7  Curvature of parabola C                           ";PAR(7)
3260 INPUT "CHANGE NO.?  TO ?   (0,0=NO CHANGES)";J,PAR(J)
3270 IF J = 0 GOTO 3290
3280 GOTO 3260
3290 PRINT"" : PRINT"              BOUNDARIES AND OPERATING DATA"
3300 PRINT"I                          V(I)"
3310 PRINT" 1  X0 left boudary   ";V(1)
3320 PRINT" 2  X4 right boundary ";V(2)
3330 PRINT" 3  Threshold to reject data, first iteration ";V(3)
3340 PRINT" 4  Threshold to reject data, remaining iterations ";V(4)
3350 PRINT" 5  Lower bound on profile values for fitting      ";V(5)
3360 PRINT" 6  Upper bound on profile values for fitting      ";V(6)
3370 PRINT" 7  EPSIL (test in equation solver)               ";V(7)
3380 PRINT" 8  Inner zone, left side    ";V(8)
```

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3390 PRINT" 9  Inner zone, right side   ";V(9)
3400 PRINT"10  Distance off of line in breakpoint search ";V(10)
3410 PRINT"11  Backup distance from estimate of corner for fitting it ";V(11)
3420 PRINT"          check that V(1) < V(8) < V(9) < V(2)"
3430 INPUT "CHANGE NO.?   TO ?    (0,0=NO CHANGES)";J,V(J)
3440 IF J = 0 GOTO 3460
3450 GOTO 3430
3460 PRINT"I                                          JV(I)"
3470 PRINT" 1  LBOX half length of side of box        ";JV(1)
3480 PRINT" 2  1 for choice on 3 graphs               ";JV(2)
3490 PRINT" 4  NPAR, no. parameters to scan            ";JV(4)
3500 PRINT" 5  Width for initial profile display box ";JV(5)
3510 PRINT" 6  1 for pauses                           ";JV(6)
3520 PRINT" 7  Line number for message on 3 graphs    ";JV(7)
3530 PRINT" 8  Geometrical order. 0 if bellows on left, 1 if on right ";JV(8)
3540 PRINT" 9  Width for final display boxes (e.g. 200) ";JV(9)
3550 PRINT"10  Number of points off of line to designate breakpoint ";JV(10)
3560 PRINT"11  Time delay to view graphics (under 32000) ";JV(11)
3570 PRINT"12  Do fitting on every ? data point (1 to 4) ";JV(12)
3580 PRINT"              PROCESSING CHOICES"
3590 PRINT"13  ? Want to fit lead-in lines (1) ";JV(13)
3600 PRINT"14  ? Want automatic CORNER designation (1) ";JV(14)
3610 PRINT"15  ? How many fitting iterations on CORNER (0,1,2) ";JV(15)
3620 PRINT"16  ? Want automatic designation of WETTING points (1) ";JV(16)
3630 PRINT"17  ? How many fitting iterations on WETTING points (0,1,2) ";JV(17)
3640 PRINT"18  ? Want manual designation of all breakpoints (1) ";JV(18)
3650 PRINT"19  ? How many fitting iterations on overall profile (0,1,2) ";JV(19)
3660 PRINT"20  ? Source for initial parameters: previous profile (0), setup file (1) ";JV(20)
3670 PRINT"21  Operator is asked if result is o.k. (1) ";JV(21)
3680 INPUT "CHANGE NO. ?   TO ?   (0,0=NO CHANGE)";J,JV(J)
3690 IF J = 0 GOTO 3780 : REM  skip NHOLD
3700 GOTO 3680
3710 PRINT "     I      NHOLD(I)"
3720 FOR I=1 TO JV(4)
3730 PRINT I,NHOLD(I)
3740 NEXT I
3750 INPUT "CHANGE NO. ?   TO ?   (0,0=NO CHANGE)";J,NHOLD(J)
3760 IF J = 0 GOTO 3780
3770 GOTO 3750
3780 PRINT "     I      INCREMENTS FOR NUMERICAL DERIVATIVES(I)"
3790 FOR I=1 TO JV(4)
3800 PRINT I,DINC(I)
3810 NEXT I
3820 INPUT "CHANGE NO. ?   TO ?   (0,0=NO CHANGE)";J,DINC(J)
3830 IF J = 0 THEN GOTO 3850
3840 GOTO 3820
3850 PRINT "     I      CONVERGENCE(I)"
3860 FOR I=1 TO JV(4)
3870 PRINT I,COV(I)
3880 NEXT I
```

```
3890 INPUT "CHANGE NO. ?   TO ?   (0,0=NO CHANGE)";J,COV(J)
3900 IF J = 0 THEN GOTO 3930
3910 GOTO 3890
3920 ORDER=JV(8)-1 : REM  -1 for bellows ring on right, 0 for left side
3930 LBOX=JV(1) : X0=V(1) : X4=V(2)
3940 GOSUB 3960
3950 RETURN
3960 REM ********** Save parameters **********
3970 PRINT"? Want to save these parameters (Y) ";
3980 GOSUB 6950 : REM  Get answer
3990 IF NO THEN RETURN
4000 OPEN "O",1,PAR$
4010 FOR I=1 TO NAR:PRINT#1,PAR(I) : NEXT
4020 FOR I=1 TO NAR:PRINT#1,V(I) : NEXT
4030 FOR I=1 TO NAR:PRINT#1,JV(I) : NEXT
4040 FOR I=1 TO NAR:PRINT#1,NHOLD(I) : NEXT
4050 FOR I=1 TO NAR:PRINT#1,DINC(I) : NEXT
4060 FOR I=1 TO NAR:PRINT#1,COV(I) : NEXT
4070 CLOSE#1
4080 RETURN
4090 REM ********************************************************************************
4100 REM           Evaluate math model, "Theory"
4110 REM ************************************************
4120 REM  We model the weld profile as a piecewise continuous function,
4130 REM    consisting of straight line segments for the metal surfaces,
4140 REM    and a parabolic segment for the fillet weld.
4150 REM
4160 A1=PAR(1) : REM  slope of outer bellows ring
4170 B1=PAR(2) : REM  intercept      "
4180 X1=PAR(3) : REM  first breakpoint, corner of bellows ring
4190 X2=PAR(4) : REM  second breakpoint, wetting point of fillet on ring
4200 X3=PAR(5) : REM  third breakpoint, wetting point of fillet on endfitting
4210 B4=PAR(6) : REM  intercept of end fitting surface
4220 C=PAR(7)  : REM  curvature of parabola fitting fillet
4230 REM  Outer surface of bellows ring is line of slope A1 and intercept B1
4240 REM    Its region is border X0 to breakpoint X1=PAR(3)
4250 IF ORDER THEN IF XX < X1 THEN F=A1*XX+B1
4260 IF NOT ORDER THEN IF XX > X1 THEN F=A1*XX+B1
4270 REM  Edge of bellows ring is perpendicular to outer surface, so its
4280 REM    slope is -1/A1. Intercept B2 is calculated from common point with
4290 REM    first line at XX=X1.
4300 A2=1E+10 : IF ABS(A1) > 1E-10 THEN A2=-1/A1
4310 B2=X1*(A1-A2)+B1
4320 IF ORDER THEN IF XX >= X1 AND XX < X2 THEN F=A2*XX+B2
4330 IF NOT ORDER THEN IF XX <= X1 AND XX > X2 THEN F=A2*XX+B2
4340 REM  Third line segment is for end fitting surface: F4=A4*XX+B4
4350 REM    Take A4=A1, an assumption.
4360 IF ORDER THEN IF XX >= X3 THEN F=A1*XX+B4
4370 IF NOT ORDER THEN IF XX <= X3 THEN F=A1*XX+B4
4380 REM  Fit a parabola between X2 and X3. This parabola joins lines at X2
```

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4390 REM    and X3, so two of three parabola coefficients can be calculated
4400 IF ORDER THEN IF XX < X2 OR XX >= X3 THEN RETURN
4410 IF NOT ORDER THEN IF XX > X2 OR XX <= X3 THEN RETURN
4412 REM  this is section which calculates parabola
4420 REM !!! WARNING no provision for case with X2=X3 below. Divide by zero !!!
4430 XXXX=((X2-X3)/2)^2
4440 A=(X2*X3*(A2-A1)+X3*B2-X2*B4-C*XXXX*(X3-X2))/(X3-X2)
4450 B=(A2*X2-A1*X3+B2-B4)/(X2-X3)
4460 F=A+B*XX+C*(XX-(X2+X3)/2)^2
4480 RETURN
4490 REM*****************************************************************************
4500 REM                    Perform fitting
4510 REM*******************************************
4520 REM   fitting program - non-linear least squares
4530 REM                  -(non-linear regression analysis)
4540 M=0
4550 NPAR=JV(4) : REM  number of parameters to scan
4560 FOR J=1 TO NPAR
4570 IF NHOLD(J) = 1 GOTO 4590
4580 M=M+1
4590 NEXT J
4600 IF M = 0 THEN RETURN
4610 REM **** do MAXIT fitting iterations ****
4620 IF MAXIT = 0 THEN RETURN
4630 SCREEN 2 : ITERATIONS=0
4640 FOR IT=1 TO MAXIT
4650 SUM=0 : INCLUDED=0 : REM  for average deviation
4660 CLS
4670 PRINT "PROFILE  ";INPNAM$
4680 PRINT MESSAGE$ : REM  from MAIN
4690 PRINT "WORKING ON ITERATION  ";IT
4700 PRINT " "
4710 PRINT "PREVIOUS PARAMETER VALUES"
4720 PRINT "A1  ";PAR(1)
4730 PRINT "B1  ";PAR(2)
4740 PRINT "X1  ";PAR(3)
4750 PRINT "X2  ";PAR(4)
4760 PRINT "X3  ";PAR(5)
4770 PRINT "B4  ";PAR(6)
4780 PRINT "C   ";PAR(7)
4790 LINE(IS-2*PB+98,NS-LY-PB-1)-(IS+LX+2*PB+102,NS+PB+1),,B
4800 REM *****  initialize AMATRIX and E
4810 FOR K=1 TO M
4820 E(K)=0
4830 FOR L=K TO M
4840 AMATRIX(K,L)=0
4850 NEXT L
4860 NEXT K
```

```
4870 REM  ******************** Scan over data points ****************************
4880 FOR MX=1 TO NP STEP DELTAX
4890 C$=INKEY$:IF C$="Q" OR C$="q" THEN SCREEN 0 :PRINT"QUIT FITTING":GOTO
1520
4900 REM  calculate derivatives with numerical methods
4910 XX=X(MX) : REM     set  X
4920 REM  ***************** select area for fitting ***************
4930 REM
4940 REM     X0          ZONEL              ZONER          X4
4950 REM     | fitting    |  no fitting     |  fitting     |
4960 REM
4970 IF XX < X0 OR XX > X4 THEN GOTO 5270 : REM outer boundaries
4980 IF XX >= ZONEL AND XX <= ZONER THEN GOTO 5270 : REM inner dead zone
4990 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 5270
5000 GOSUB 4090 : REM  Theory
5010 FOT=F      : REM  initial central value
5020 FAC=PROFILE(MX)-FOT
5030 REM  ******************** Cull out bad data ********************
5040 ABFAC=ABS(FAC)
5050 IF IT=1 AND ABFAC > V(3) THEN GOTO 5270 : REM  first pass
5060 IF IT>1 AND ABFAC > V(4) THEN GOTO 5270 : REM  remaining passes
5070 K=0
5080 FOR JJ=1 TO NPAR
5090 IF NHOLD(JJ) = 1 GOTO 5150
5100 K=K+1
5110 PAR(JJ)=PAR(JJ)+DINC(JJ)
5120 GOSUB 4090 : REM  theory
5130 DERIV(K)=(F-FOT)/DINC(JJ)
5140 PAR(JJ)=PAR(JJ)-DINC(JJ)
5150 NEXT JJ
5160 REM  derivatives are done
5170 SUM=SUM+ABFAC : INCLUDED=INCLUDED+1
5180 REM  plot difference between data and theory
5190 PSET(IS+( INT( (X(MX)-XMIN)*XSCALE ) -1)+100,NS-LY/2+INT(FAC*YSCALE))
5200 FOR K=1 TO M
5210 WDERIV=DERIV(K)
5220 E(K)=E(K)+WDERIV*FAC
5230 FOR L=K TO M
5240 AMATRIX(K,L)=AMATRIX(K,L)+WDERIV*DERIV(L)
5250 NEXT L
5260 NEXT K
5270 NEXT MX
5280 REM  fill in lower half of AMATRIX
5290 FOR K=1 TO M
5300 FOR L=K+1 TO M
5310 AMATRIX(L,K)=AMATRIX(K,L)
5320 NEXT L
5330 NEXT K
5340 REM    AMATRIX and E are now loaded
```

```
5350 REM ************************************************************
5360 REM  Solve for new parameter values
5370 REM
5380 REM  Gauss elimination method
5390 REM  "Numerical Methods in Fortran" - Mc Cormick, J.M. and
5400 REM  Salvadori, M.G., Prentice-Hall,  Page 205
5410 REM  N.B. Matrix A has positive and non-zero elements on the diagonal
5420 REM **********
5430 EPSIL=V(7)
5440 FOR I=1 TO M
5450 IF AMATRIX(I,I) < EPSIL THEN GOTO 8660 : REM error
5460 NEXT I
5470 N=M
5480 IF N = 1 THEN GOTO 5690
5490 FOR I=1 TO N-1
5500 L=I+1
5510 FOR J=L TO N
5520 IF ABS(AMATRIX(J,I)) < EPSIL GOTO 5580
5530 AL=AMATRIX(J,I)/AMATRIX(I,I)
5540 FOR K=L TO N
5550 AMATRIX(J,K)=AMATRIX(J,K)-AMATRIX(I,K)*AL
5560 NEXT K
5570 E(J)=E(J)-E(I)*AL
5580 NEXT J
5590 NEXT I
5600 E(N)=E(N)/AMATRIX(N,N)
5610 FOR I=1 TO N-1
5620 K=N-I
5630 FOR J=K+1 TO N
5640 E(K)=E(K)-E(J)*AMATRIX(K,J)
5650 NEXT J
5660 E(K)=E(K)/AMATRIX(K,K)
5670 NEXT I
5680 GOTO 5700
5690 E(1)=E(1)/AMATRIX(1,1)
5700 REM  continue
5710 REM  parameter changes are now stored in E
5720 PRINT " "
5730 IF INCLUDED=0 THEN CLOSE
                : PRINT"ERROR in fitting - NO POINTS INCLUDED" : END
5740 MISFIT=SUM/INCLUDED
5750 PRINT "AVE. MISFIT  ";MISFIT
5760 REM  update parameters and check for convergence
5770 NCOV=0
5780 K=0
5790 FOR J=1 TO NPAR
5800 IF NHOLD(J) = 1 THEN GOTO 5850
5810 K=K+1
5820 CHANGE=E(K)
5830 IF ABS(CHANGE) < COV(J) THEN NCOV=NCOV+1
```

```
5840 PAR(J)=PAR(J)+CHANGE
5850 NEXT J
5860 PRINT"" : PRINT "NEW PARAMETER VALUES"
5870 PRINT "A1  ";PAR(1)
5880 PRINT "B1  ";PAR(2)
5890 PRINT "X1  ";PAR(3)
5900 PRINT "X2  ";PAR(4)
5910 PRINT "X3  ";PAR(5)
5920 PRINT "B4  ";PAR(6)
5930 PRINT "C   ";PAR(7)
5940 IF NCOV = M THEN GOTO 6000 : REM  test if all parameters have converged
5950 IF JV(6) = 1 THEN INPUT C$ : REM  pause
5960 ITERATIONS=ITERATIONS+1
5970 NEXT IT                    : REM  end of iteration loop.
5980 SCREEN 0
5990 RETURN
6000 IF JV(6) = 1 THEN INPUT C$ : REM  pause
6010 SCREEN 0
6020 RETURN
6030 REM*************************************************************************
6040 REM       Draw box on Compaq screen
6050 REM**************************************
6060 REM  Box is to be drawn centered on point (IBOX,JBOX)
6070 REM  Length of side of box is 2*LBOX
6080 LINE(IBOX-LBOX,JBOX-LBOX)-(IBOX+LBOX,JBOX+LBOX),,B
6090 RETURN
6100 REM ************************************************************************
6110 REM          Automatic designation of CORNER breakpoint
6120 REM ************************************************************
6130 REM   track along bellows ring and monitor deviations
6140 REM  ***************** select area ***************
6150 REM
6160 REM           ZONEL                  ZONER
6170 REM             <     active area      >
6180 REM
6190 ISTART=0
6200 FOR MX=1 TO NP
6210 XX=X(MX) : REM     set  X
6220 IF XX < ZONEL OR XX > ZONER THEN GOTO 6250 : REM outside brakepoint zone
6230 IF ISTART=0 THEN ISTART=MX : REM  First data point within zone
6240 ISTOP=MX : REM  will be left at last data point in zone
6250 NEXT MX
6260 REM the above is needed for "calibrated" data only
6270 A1=PAR(1) : REM  slope of outer bellows ring
6280 B1=PAR(2) : REM  intercept      "
6290 B4=PAR(6) : REM  intercept of end fitting surface
6300 REM  Outer surface of bellows ring is line of slope A1 and intercept B1
6310 REM *** find breakpoint from left to right
6320 IF NOT ORDER THEN GOTO 6450 : REM  skip this for reversed geometry
6330 SLOPE=A1 : INTERCEPT=B1 : GOSUB 9100 : REM  draw best fit lead-in line
```

```
6340 REM  follow line and look for deviations
6350 ICOUNT=0
6360 FOR MX=ISTART TO ISTOP
6370 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 6420
6380 XX=X(MX) : REM      set  X
6390 F=A1*XX+B1
6400 IF ABS(PROFILE(MX)-F) > V(10) THEN ICOUNT=ICOUNT+1
6410 IF ICOUNT >= JV(10) THEN GOTO 6430
6420 NEXT MX
6430 MARKBREAK(1)=MX
6440 GOTO 6570
6450 REM *** find breakpoint from right to left for reversed order
6460 SLOPE=A1 : INTERCEPT=B1 : GOSUB 9100 : REM  draw best fit lead-in line
6470 REM  follow line and look for deviations
6480 ICOUNT=0
6490 FOR MX=ISTOP TO ISTART STEP -1
6500 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 6550
6510 XX=X(MX) : REM      set  X
6520 F=A1*XX+B1
6530 IF ABS(PROFILE(MX)-F) > V(10) THEN ICOUNT=ICOUNT+1
6540 IF ICOUNT >= JV(10) THEN GOTO 6560
6550 NEXT MX
6560 MARKBREAK(1)=MX
6570 REM ***** Plot result *****
6580 REM  assume that estimate for first breakpoint overshot the mark
6590 THETA=ATN(PAR(1)) : OVERSHOOT=ABS(V(10)*COS(THETA)*SIN(THETA))
6600 IF ORDER THEN XX=X(MARKBREAK(1))-OVERSHOOT
6610 IF NOT ORDER THEN XX=X(MARKBREAK(1))+OVERSHOOT
6620 I=INT( (XX-XMIN)*XSCALE )
6630 J=INT( (PROFILE(MARKBREAK(1))-YMIN)*YSCALE )
6640 IBOX=IS+I : JBOX=NS-J : GOSUB 6030 : REM  draw box at designated point
6650 PAR(3)=XX
6660 IF JV(6) = 1 THEN INPUT C$          : REM  pause
6670 RETURN
6680 REM ************************************************************************
6690 REM              Manual designation of breakpoints
6700 REM ************************************************
6710 LOCATE 1,1 : PRINT"? Want to adjust breakpoints (Y) ";
6720 GOSUB 6950 : REM  Get answer
6730 IF NO THEN RETURN
6740 REM  Move bar horizontally to indicate breakpoints.
6750 LOCATE 20,1 : PRINT"Use arrow keys to move bar."
6760 LOCATE 21,1
6770 PRINT"Position bar on CORNER of bellows ring and then press Enter       "
6780 I=IS+INT(LX/2) : J1=NS-LY : J2=NS : SIZE=2
6790 GOSUB 8280 : REM  move bar
6800 PAR(3)=XDESIGNATED : REM  breakpoint X1
6810 LOCATE 21,1
6820 PRINT"Position bar on WETTING point on BELLOWS RING and then press Enter"
6830 I=I+1 : IF NOT ORDER THEN I=I-2 : REM  so that previous bar is not erased
```

```
6840 GOSUB 8280 : REM  move bar
6850 PAR(4)=XDESIGNATED : REM  breakpoint X2
6860 LOCATE 21,1
6870 PRINT"Position bar on WETTING point on END FITTING and then press Enter "
6880 I=I+1 : IF NOT ORDER THEN I=I-2 : REM  so that previous bar is not erased
6890 GOSUB 8280 : REM  move bar
6900 PAR(5)=XDESIGNATED : REM  breakpoint X3
6910 LOCATE 23,1 : PRINT"? Want to redo these breakpoints (Y) ";
6920 GOSUB 6950 : REM  Get answer
6930 IF YES THEN GOTO 6680
6940 RETURN
6950 REM ************************************************************************
6960 REM              Get answer to question ? (YES OR NO)
6970 REM ************************************************
6980 REM  true value is -1. not true is 0
6990 C$=INKEY$ : IF C$="" GOTO 6990
7000 IF C$="Q" OR C$="q" THEN SCREEN 0 : CLOSE : PRINT "Quit": END
7010 PRINT C$
7020 IF C$="Y" OR C$="y" THEN YES=-1 : NO=0
7030 IF C$ >< "Y" AND C$ >< "y" THEN YES=0 : NO=-1
7040 RETURN
7050 REM ************************************************************************
7060 REM         Automatic designation of WETTING points
7070 REM ************************************************
7080 REM   track along face of bellows ring and monitor deviations
7090 REM    "    "  end fitting          "   "        "
7100 REM ********** select area **********
7110 REM
7120 REM           ZONEL                 ZONER
7130 REM             <     active area      >
7140 REM
7150 IF ORDER THEN ZONEL=PAR(3) : ZONER=V(9)
7160 IF NOT ORDER THEN ZONEL=V(8) : ZONER=PAR(3)
7170 ISTART=0
7180 FOR MX=1 TO NP
7190 XX=X(MX) : REM     set  X
7200 IF XX < ZONEL OR XX > ZONER THEN GOTO 7230 : REM outside brakepoint zone
7210 IF ISTART=0 THEN ISTART=MX : REM  First data point within zone
7220 ISTOP=MX : REM  will be left at last data point in zone
7230 NEXT MX
7240 REM the above is needed for "calibrated" data only
7250 A1=PAR(1) : REM  slope of outer bellows ring
7260 B1=PAR(2) : REM  intercept      "
7270 B4=PAR(6) : REM  intercept of end fitting surface
7280 X1=PAR(3) : REM  first breakpoint, corner of bellows ring
7290 A2=1E+10 : IF ABS(A1) > 1E-10 THEN A2=-1/A1
7300 B2=X1*(A1-A2)+B1
7310 REM ********** wetting point on face of bellows ring **********
7320 SLOPE=A2 : INTERCEPT=B2 : GOSUB 9100 : REM  draw line for face of ring
7330 REM ********** track along line and monitor deviation **********
```

```
7340 ICOUNT=0 : REM  number of significant deviations
7350 IF NOT ORDER THEN GOTO 7450 : REM  for bellows ring on right
7360 REM  *** move from left to right for bellows ring on left ****
7370 FOR MX=ISTART TO ISTOP
7380 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 7420
7390 XX=X(MX) : F=A2*XX+B2
7400 IF ABS(PROFILE(MX)-F) > V(10) THEN ICOUNT=ICOUNT+1
7410 IF ICOUNT >= JV(10) THEN GOTO 7430
7420 NEXT MX
7430 MARKBREAK(2)=MX
7440 GOTO 7530
7450 REM *** move from right to left for bellows ring on right ****
7460 FOR MX=ISTOP TO ISTART STEP -1
7470 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 7510
7480 XX=X(MX) : F=A2*XX+B2
7490 IF ABS(PROFILE(MX)-F) > V(10) THEN ICOUNT=ICOUNT+1
7500 IF ICOUNT >= JV(10) THEN GOTO 7520
7510 NEXT MX
7520 MARKBREAK(2)=MX
7530 REM since X1 was trimmed up, find new MARKBREAK(1)
7540 FOR MX=1 TO NP
7550 IF X(MX) >= PAR(3) THEN GOTO 7570 : REM  closest data point
7560 NEXT MX
7570 MARKBREAK(1)=MX
7580 GOSUB 8790 : REM  find wetting point on end fitting. Get MARKBREAK(3)
7590 REM  **** Show all three breakpoints ****
7600 FOR IBREAK=1 TO 3
7610 XX=X(MARKBREAK(IBREAK))
7620 I=INT( (XX-XMIN)*XSCALE )
7630 J=INT( (PROFILE(MARKBREAK(IBREAK))-YMIN)*YSCALE )
7640 IBOX=IS+I : JBOX=NS-J : GOSUB 6030 : REM  draw box at designated point
7650 IF IBREAK > 1 THEN PAR(2+IBREAK)=XX
7660 NEXT IBREAK
7670 IF JV(6) = 1 THEN INPUT C$          : REM  pause
7680 RETURN
7690 REM ********************************************************************************
7700 REM                    Convert to ASCII
7710 REM ****************************************
7720 A$="
7730 BB$="00"
7740 IF A! > 9.5 THEN BB$="0"
7750 IF A! > 99.5 THEN BB$=""
7760 A!=A!/10
7770 RES!=A!-INT(A!)
7780 RES!=RES!*10
7790 A!=INT(A!)
7800 A$=CHR$(RES!+48)+A$
7810 IF A! > 0 THEN GOTO 7760
7820 A$=BB$+A$
7830 RETURN
```

```
7840 REM ************************************************************************
7850 REM            Manual designation of boundaries
7860 REM ************************************************
7870 GOSUB 1910 : REM  Show profile
7880 REM  Move bar horizontally to indicate breakpoints.
7890 LOCATE 1,1 : PRINT"? Need to reset boundaries (Y) ";
7900 GOSUB 6950 : REM  Get answer
7910 IF NO THEN RETURN
7920 LOCATE 20,1 : PRINT"Use arrow keys to move bars."
7930 LOCATE 21,1
7940 PRINT"Position bar on LEFT boundary of good data and then press Enter   "
7950 I=IS : J1=NS-LY : J2=NS : SIZE=2
7960 GOSUB 8280 : REM  move bar
7970 V(1)=XDESIGNATED : REM  boundary X0
7980 LOCATE 21,1
7990 PRINT"Position bar on RIGHT boundary of good data and then press Enter  "
8000 I=IS+LX
8010 GOSUB 8280 : REM  move bar
8020 V(2)=XDESIGNATED : REM  right boundary X4
8030 LOCATE 21,1
8040 PRINT"Position bar on LEFT LEAD-IN zone and then press Enter           "
8050 I=IS+INT(LX/2) : REM  assumes a good starting point is in middle
8060 GOSUB 8280 : REM  move bar
8070 V(8)=XDESIGNATED : REM  left zone point ZONEL
8080 LOCATE 21,1
8090 PRINT"Position bar on RIGHT LEAD-IN zone and then press Enter          "
8100 I=IS+INT(LX/2) : REM  assumes a good starting point is in middle
8110 GOSUB 8280 : REM  move bar
8120 V(9)=XDESIGNATED : REM  right zone point ZONER
8130 REM  Move horizontal bar vertically to indicate boundaries of good data."
8140 LOCATE 21,1
8150 PRINT"Position bar on BOTTOM boundary of good data and then press Enter "
8160 I1=IS : I2=IS+LX : J=NS+1 : REM  +2 to save YMIN
8170 GOSUB 8470 : REM  move bar
8180 V(5)=YDESIGNATED : REM  bottom boundary
8190 LOCATE 21,1
8200 PRINT"Position bar on TOP boundary of good data and then press Enter    "
8210 J=NS-LY-2 : REM  -2 to avoid deleting YMAX
8220 GOSUB 8470 : REM  move bar
8230 V(6)=YDESIGNATED : REM  top boundary
8240 LOCATE 23,1 : PRINT"? Want to redo (Y) ";
8250 GOSUB 6950 : REM  Get answer
8260 IF YES THEN GOTO 7870
8270 RETURN
```

```
8280 REM ************************************************************************
8290 REM                    Designate X manually
8300 REM ****************************************
8310 REM  input is I. output is XDESIGNATED. move vertical bar on screen.
8320 LOCATE 22,1 : PRINT"Position X ";
8330 LOCATE 22,14 : PRINT USING"####.#";(I-IS)/XSCALE+XMIN;
8340 LINE (I,J1)-(I,J2),1 : REM  new bar
8350 ISAV=I
8360 C$=INKEY$ : IF C$="" THEN GOTO 8360
8370 IF C$="Q" OR C$="q" THEN SCREEN 0 : CLOSE : PRINT"Quit" : END
8380 IF C$=CHR$(0)+CHR$(77) THEN I=I+2*SIZE : REM  right arrow key
8390 IF C$=CHR$(0)+CHR$(75) THEN I=I-2*SIZE : REM  left arrow key
8400 IF C$=CHR$(13) THEN GOTO 8450 : REM  Enter key to escape
8410 LINE (I,J1)-(I,J2),1 : REM  new bar
8420 LINE (ISAV,J1)-(ISAV,J2),0 : REM  hide old bar
8430 LOCATE 22,14 : PRINT USING"####.#";(I-IS)/XSCALE+XMIN;
8440 GOTO 8350
8450 XDESIGNATED=(I-IS)/XSCALE+XMIN
8460 RETURN
8470 REM ************************************************************************
8480 REM                    Designate Y manually
8490 REM ****************************************
8500 REM  input is J. output is YDESIGNATED. move horizontal bar on screen.
8510 LOCATE 22,1 : PRINT"Position Y ";
8520 LOCATE 22,14 : PRINT USING"####.#";(NS-J)/YSCALE+YMIN;
8530 LINE (I1,J)-(I2,J),1 : REM  new bar
8540 JSAV=J
8550 C$=INKEY$ : IF C$="" THEN GOTO 8550
8560 IF C$="Q" OR C$="q" THEN SCREEN 0 : CLOSE : PRINT"Quit" : END
8570 IF C$=CHR$(0)+CHR$(72) THEN J=J-SIZE : REM  up arrow key
8580 IF C$=CHR$(0)+CHR$(80) THEN J=J+SIZE : REM  down arrow key
8590 IF C$=CHR$(13) THEN GOTO 8640 : REM  Enter key to escape
8600 LINE (I1,J)-(I2,J),1 : REM  new bar
8610 LINE (I1,JSAV)-(I2,JSAV),0 : REM  hide old bar
8620 LOCATE 22,14 : PRINT USING"####.#";(NS-J)/YSCALE+YMIN;
8630 GOTO 8540
8640 YDESIGNATED=(NS-J)/YSCALE+YMIN
8650 RETURN
8660 REM ************************************************************************
8670 REM                      Fitting error
8680 REM ****************************************
8690 PRINT"AMATRIX(";I;",";I;") < EPSIL   fatal error"
8700 PRINT CHR$(7) : REM  beep
8710 IF ORDER THEN PRINT "CHECK IF X1 < X2 < X3"
8720 IF NOT ORDER THEN PRINT "CHECK IF X1 > X2 > X3"
8730 PRINT"Check data boundaries and weld zone"
8740 PRINT"Check that breakpoints in PARAMS are compatible with X values in data"
8750 INPUT"Press Enter to begin again from start. Use set-up mode";C$
8760 SETUP=-1 : REM  true value, to perform set-up
8770 SCREEN 0 : GOTO 580
```

```
8790 REM ************************************************************************
8800 REM      Automatic designation of wetting point on end fitting
8810 REM ************************************************************
8820 REM  *** find wetting point on end fitting ****
8830 IF ORDER THEN GOTO 8970 : REM  (for bellows ring on left)
8840 REM  this is for bellows ring on right.
8850 SLOPE=A1 : INTERCEPT=B4 : GOSUB 9100 : REM  draw fitted leadin line
8860 REM  follow line from left to right and look for deviations
8870 ICOUNT=0
8880 FOR MX=ISTART TO ISTOP
8890 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 8940
8900 XX=X(MX) : REM      set  X
8910 F=A1*XX+B4
8920 IF ABS(PROFILE(MX)-F) > V(10) THEN ICOUNT=ICOUNT+1
8930 IF ICOUNT >= JV(10) THEN GOTO 8950
8940 NEXT MX
8950 MARKBREAK(3)=MX
8960 RETURN
8970 REM *** find breakpoint from right to left. Bellows ring on left ***
8980 SLOPE=A1 : INTERCEPT=B4 : GOSUB 9100 : REM  draw best fit lead-in line
8990 REM  follow line and look for deviations
9000 ICOUNT=0
9010 FOR MX=ISTOP TO ISTART STEP -1 : REM  from right to left
9020 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 9070
9030 XX=X(MX) : REM      set  X
9040 F=A1*XX+B4
9050 IF ABS(PROFILE(MX)-F) > V(10) THEN ICOUNT=ICOUNT+1
9060 IF ICOUNT >= JV(10) THEN GOTO 9080
9070 NEXT MX
9080 MARKBREAK(3)=MX
9090 RETURN
9100 REM ************************************************************************
9110 REM              draw search lines for breakpoints
9120 REM ************************************************
9130 REM  input SLOPE, INTERCEPT
9140 ISTART2=0
9150 FOR MX=1 TO NP
9160 IF PROFILE(MX) < V(5) OR PROFILE(MX) > V(6) THEN GOTO 9240
9170 XX=X(MX) : REM      set  X
9180 F=SLOPE*XX+INTERCEPT
9190 III=INT( (XX-XMIN)*XSCALE )
9200 JJJ=INT( (F-YMIN)*YSCALE )
9210 IF JJJ < -PB OR JJJ > LY+PB THEN GOTO 9240 : REM  stay within display box
9220 IF ISTART2=0 THEN ISTART2=1 : I1=III : J1=JJJ : REM  First point within box
9230 I2=III : J2=JJJ : REM  will be left at last point in box
9240 NEXT MX
9250 REM  can't plot at data points or see breaks where data missing
9260 LINE (IS+I1,NS-J1 ) - (IS+I2,NS-J2 )
9270 RETURN
```